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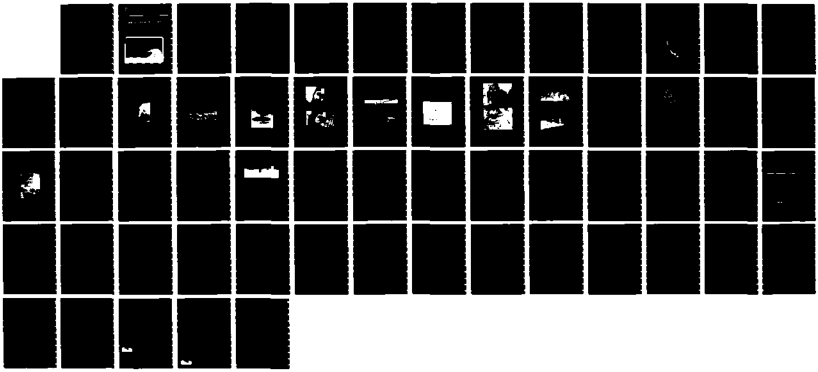

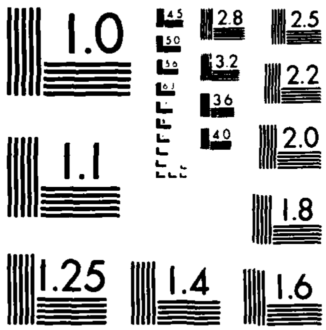

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US Army Corps
of Engineers
Los Angeles District

COAST OF CALIFORNIA
STORM AND TIDAL WAVES STUDY

ANNUAL REPORT 1985

CCSTWS 86-3
July 1986

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SAN DIEGO REGION ANNUAL REPORT

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

THIS IS THE THIRD ANNUAL REPORT OF THE CORPS OF ENGINEERS' LANDMARK STUDY OF THE COAST OF CALIFORNIA. IT IS A REPORT OF THE PROGRESS OF THE STUDY IN 1985. THE REPORT IS NON-TECHNICAL AND IS INTENDED AS AN INTRODUCTION TO THE STUDY FOR GENERALISTS AND SPECIALISTS ALIKE. THE COAST OF CALIFORNIA STORM AND TIDAL WAVES STUDY (CCSTWS) IS A COOPERATIVE EFFORT, DESIGNED TO IMPROVE OUR PRACTICAL KNOWLEDGE OF HOW CALIFORNIA'S COAST IS CHANGING. THIS PROGRESS REPORT SUMMARIZES THE WORK CONDUCTED IN THE

SAN DIEGO REGION IN 1985.

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Coast of California Storm and Tidal Waves Study

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JULY 1986

THE COAST OF CALIFORNIA STORM AND TIDAL WAVES STUDY

PREFACE

This is the third annual report of the Corps of Engineers' landmark study of the coast of California. It is a report of progress made during 1985.

The report is non-technical, and is intended as an introduction to the study for generalists and specialists alike. Those interested in the technical findings of the study may request additional reports. The reports prepared during 1985 are listed following this preface. They may be obtained by writing either the Los Angeles or the San Francisco District Offices:

U. S. Army Corps of Engineers
Los Angeles District
Coastal Resources Branch, SPLPD-C
ATTN: CCSTWS Project Manager
P.O. Box 2711
Los Angeles, California 90053-2325
(213) 894-5170

U. S. Army Corps of Engineers
San Francisco District
Water Resources Branch, SPNPE-W
ATTN: CCSTWS Project Manager
211 Main Street
San Francisco, CA 94105
(415) 974-0463

If you would like your name added to the mailing list for CCSTWS technical publications, please fill out and mail the request form at the end of this report.

The CCSTWS is a cooperative effort, intended to improve our practical knowledge of how California's coast is changing. We welcome participation in this study from both the scientific community and the general public.

TECHNICAL PUBLICATIONS FOR 1985

CCSTWS 85-5: Geotechnical Data Inventory, Southern California Coastal Zone. December 1985.

CCSTWS 85-6: Southern California Shoreline Socioeconomic Data Summary. December 1985.

CCSTWS 85-7: Meteorological Data Inventory, Southern California Coastal Zone. December 1985.

CCSTWS 85-8: Hydrologic Data Inventory, Southern California Coastal Zone. December 1985.

CCSTWS 85-9: Hydraulic Data Inventory, Southern California Coastal Zone. December 1985.

CCSTWS 85-10: Shoreline Movement Data Report, Portuguese Point to the Mexican Border (1852-1982). December 1985.

CCSTWS 86-1: Southern California Coastal Processes Data Summary. January 1986.

CCSTWS 86-2: Southern California Coastal Photography and Beach Profile Index. January 1986.

These reports summarize the data available in hundreds of major reports and articles on the subjects covered. They are available on a limited distribution basis to interested researchers, planners, and engineers. Working from these reviews and reports of new data (e.g., CCSTWS 85-10, 86-2), it is possible to identify data gaps and to develop plans for future study.

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INTRODUCTION

This is the third annual report of the Coast of California Storm and Tidal Waves Study (CCSTWS). The U. S. Army Corps of Engineers has undertaken this study to gain a better understanding of the processes affecting coastal erosion and buildup of sediment along the entire 1,100-mile California coast. The study is a response to the critical need for information about the changing shoreline, information which will be used by planners and coastal engineers to protect property and develop stable low-maintenance harbor and shore-protection facilities.

STUDY OBJECTIVES

California's shoreline is an immensely valuable natural resource, used by hundreds of millions of people for their residences, their livelihood, and as a source of recreation. Harbors, piers, businesses, and residences which have been built on the shoreline are valued in the tens of billions of dollars. Hundreds of millions of dollars have been invested in projects to protect the shoreline from erosion, or to prevent waves from attacking developed areas — everything from small craft harbors to railroads. To protect these resources, the forces affecting the shoreline must be well understood, and shoreline changes must be predictable. A systematic analysis of the entire shoreline has been needed for many years. The Coast of California Storm and Tidal Waves Study (CCSTWS) is a response to this need.

The focus of CCSTWS is on California's beaches: (1) on how sediment (sand) is supplied to the beach from cliffs and rivers, (2) on how beaches are eroded by wind, tides, waves, and currents, and (3) on how human development has influenced these processes. CCSTWS is the first study of its kind, and probably the most comprehensive effort ever undertaken to understand the shoreline and how it changes.

To work efficiently, it is necessary to catalogue and review what is already known about the coast, thus avoiding duplication of effort. One objective of the Coast of California Storm and Tidal Waves Study has been to review all major research on the coast. Beginning with an understanding of current knowledge, the next objective is to plan research to fill in the data gaps in a systematic way. CCSTWS is the first effort to describe the entire California shoreline in detail. The most important part of this systematic study is collecting data on shoreline change in recent history and understanding the factors which cause these changes.

Once the shoreline is adequately described and the factors influencing shoreline change are identified, the focus of study will shift to developing a sediment budget (Figure 1) for each littoral cell within the six regions of the coast (Figure 2). The sediment budget will be a mathematical model, a model which can be used to evaluate the impacts of proposed structures such as jetties and breakwaters on adjacent beaches, or which can help predict where storm waves from a particular storm may threaten beaches and development on the coast. Having a numerical model of coastal processes in each region will thus make it possible to predict future shoreline changes.

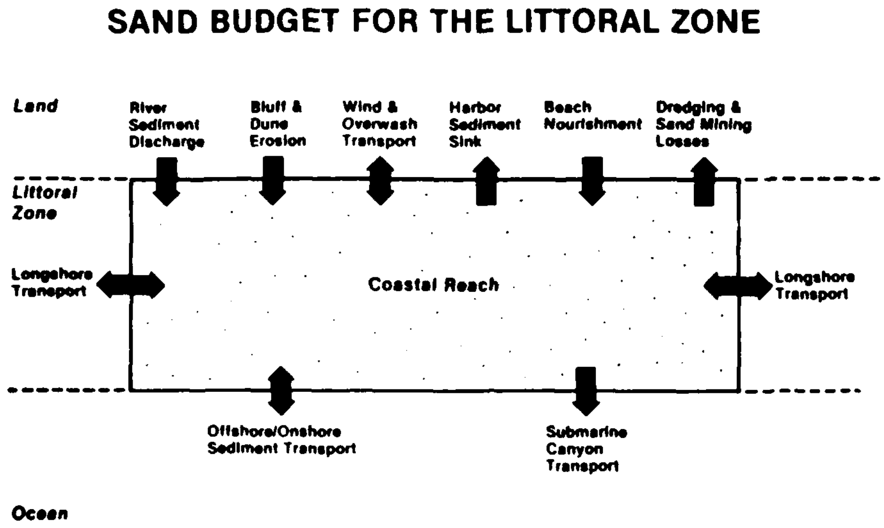


Figure 1. A conceptualization of the "sediment budget" for a littoral cell or zone. Arrows indicate the ways in which sediment is added to or removed from a cell, a self-contained area of coastline.

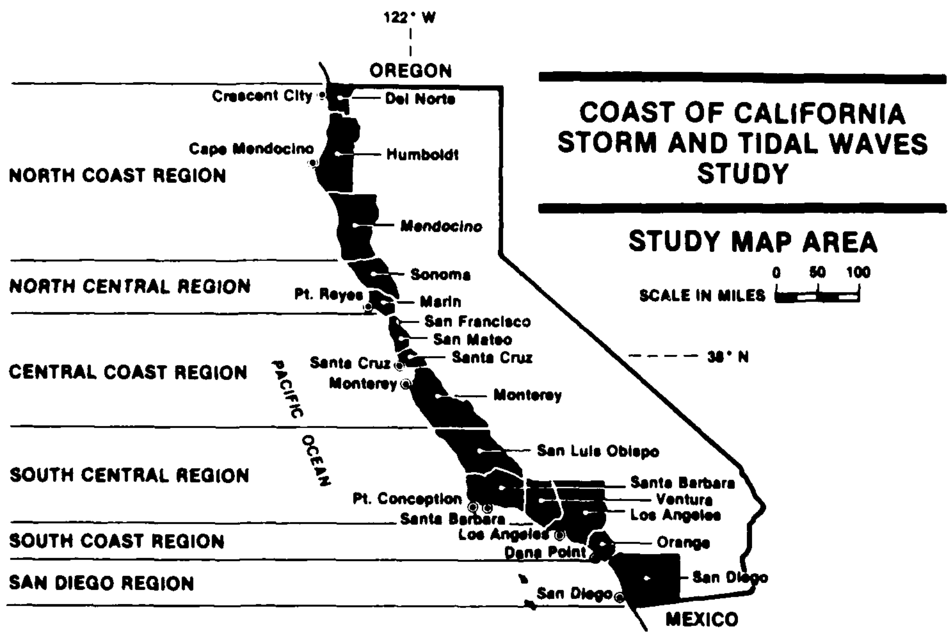


Figure 2. The six regions of California's coast, as designated by CCSTWS study plans.

THE HISTORY OF CCSTWS

During the winter of 1980, several massive storms struck the California shoreline, with damages in the hundreds of millions of dollars. Beaches were eroded, piers lost, cliffs undermined, houses washed into the sea. The storms demonstrated that current knowledge of the shoreline was inadequate. Although shore protection efforts were successful in many areas, planners and engineers, working with inadequate data, had not been able to protect many coastal structures.

In response, Congress directed the Corps of Engineers to initiate a study, originally focused on the shoreline from Dana Point to San Diego (the San Diego Region). In 1983, this study was expanded to include the entire California shoreline. The four study objectives are:

* To quantify sediment sources, sinks, and transport characteristics,
* To quantify and interpret past shoreline changes,
* To establish and test techniques for predicting how the shoreline will respond to the forces acting on it, including response to human activity, and
* To provide for rapid dissemination of information from the study to all interested researchers.

Study began in the San Diego Region in 1983, with extensive field data collection efforts underway by early in the year. The focus remained on this region until 1985, when the lessons learned in the San Diego region were applied to developing plans for studying the rest of the shoreline.

THE SCOPE OF STUDY EFFORTS, 1985

In the annual reports for 1983 and 1984, the six regions of the California coast were described in detail (Figure 2), and the study scope was outlined. The regions were delineated on the basis of both scientific and administrative considerations. The six regions differ in terms of weather, geography, geology, extent of development, and exposure to storms; study by region is thus appropriate. In addition, the three northern regions fall within the boundaries of the Corps' San Francisco District, while the southern ones are in the Los Angeles District.

The CCSTWS covers a wide range of subjects in six related fields:

* Coastal Processes
* Geomorphology
* River Hydrology and Hydraulics
* Oceanography and Meteorology
* Survey and Mapping

Descriptions of the study plans for each of these fields can be found in previous annual reports.

Prior to 1985, the emphasis of study had been on the San Diego Region. In 1985, enough had been learned in this region to make it possible to expand the study to all six regions of the California coast. CCSTWS had two emphases in 1985: continued field study in the San Diego Region, and detailed planning for the study of the other five regions, covering about 1,000 miles of coastline.

THE STUDY PROCESS

CCSTWS followed a planning process common to large-scale applied science studies. First, existing knowledge is reviewed to identify unanswered questions and identify data gaps. Field research is then designed to answer these questions and fill the data gaps. Third, with an adequate data base, the relationships between the shoreline changes observed and the forces acting on the coast can be explored. From this, quantitative relationships which have been developed to explain the interaction of waves and shore can be expanded. Fourth, these expanded relationships can be used to make more accurate predictions about shoreline change, the predictions being verified using numerical models or field studies of beach conditions. After testing, the models can be refined and then used as tools for engineering. These tools can then be used for design of structures and for predicting the impact of structures on the shoreline.

Following this basic pattern of field research, analysis, model testing and refinement, a first step is to determine what data need to be considered. CCSTWS staff, in consultation with experts from other government agencies and from the major universities and research groups in California, have established a basic study scope (Table 1). Data about all of the topics listed on table 1 are needed in order to develop a full understanding of how the shoreline is changing and how various forces contribute to that change.

In 1985, CCSTWS field data collection efforts in the San Diego Region have added to the data base in each of these areas. At the same time, in planning for study expansion, CCSTWS staff and associates in other institutions have compiled a massive bibliography of existing works on these subjects. The major works listed in this bibliography of several thousand entries have been reviewed, and available data about these subjects have been summarized. These summaries have been published and are available to interested researchers.

These two efforts, field data collection in the San Diego Region and planning for study expansion, are the subject of this annual report.

Table 1. The scope of CCSTWS data collection.

Data Category	Specific Subjects Covered by CCSTWS Study
Coastal Processes	a. Seasonal and long-term amounts of sediment being transported onshore and offshore. b. Historic changes in onshore and offshore transport. c. Seasonal and long-term amounts of sediment being transported along the shoreline (upcoast and downcoast). d. Nearshore and longshore currents. e. Sediment brought inland via overwash of beaches. f. Sediment trapped or transported by/in harbors and bays. g. Wave climate data, including offshore sea, swell, tides, and tsunamis. h. Factors affecting (transforming) waves as they approach the shore. i. Wave hindcast data. j. Water level changes, including tides, extreme tidal events such as storm tides, and sea-level changes. k. Beach and shore erosion, both long-term and seasonal. l. A sediment budget for each littoral cell in the region.
Geomorphology	a. Coastal geologic f atures: dunes, headlands, rocks, estuaries, and others. b. Inland and offshore geologic features. c. Sediment sources and characteristics. d. Geologic processes. e. Land mass changes such as subsidence and uplift, as well as tectonic movement. f. Sand and gravel mining in coastal rivers and streams. g. Wind generated sediment transport.
River Hydrology and Hydraulics	a. River flows and sediment discharge rates. b. Drainage basins. c. Historic flood events.
Regional Socioeconomics	a. Coastal erosion problems. b. Review of land use and value in the coastal zone.

Table 1, continued

Data Category	Specific Subjects Covered by CCSTWS Study
Oceanography and Meteorology	a. Wind climate, including major storms, seasonal and long-term trends, and local wind effects. b. Major ocean currents. c. Climate and rainfall history.
Survey and Mapping	a. Aerial photography. b. Historic mapping efforts. c. Inventory of beach profiles. d. Shoreline profile and beach changes.

CCSTWS ACTIVITIES, 1985

In 1985, the CCSTWS focused on both field data collection and on planning for study expansion to all regions of the coast. Some of the activities involved in these efforts are illustrated below.

Figure 3. Field Data Collection in the San Diego Region: The Submarine Canyon Study. A member of the dive team for the Submarine Canyon Study places areference rod into the ocean floor at the flat, delta-like head of a submarine canyon.

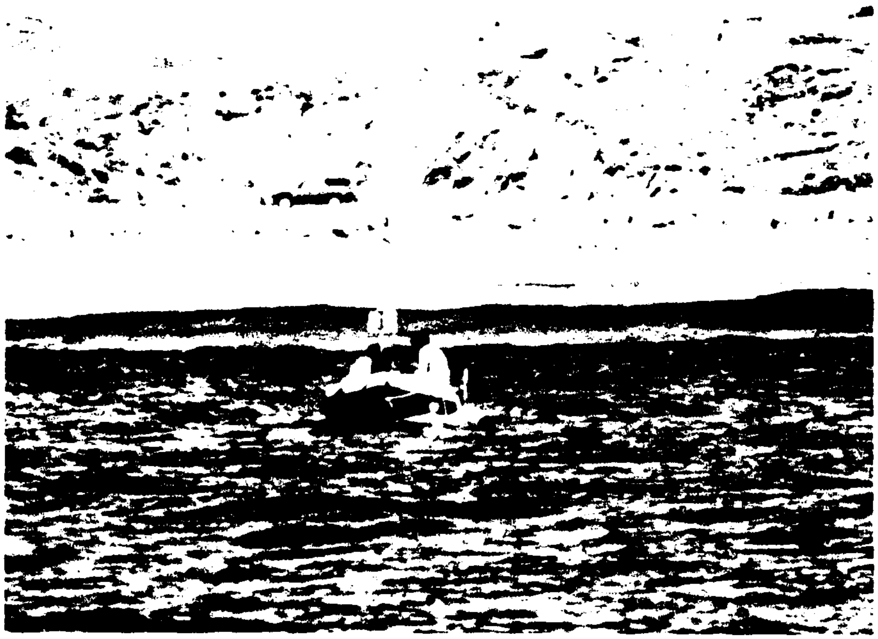


Figure 4. Field Data Collection in the San Diego Region: Taking Fathometer Readings off the San Diego Region Coast. Working from a small survey boat, researchers take depth readings to develop profiles of the littoral zone. Seasonal profiles taken repeatedly along the same set of profile lines reveal buildup and erosion of the sediments along the shoreline and in the nearshore zone. Profiles are taken to about a depth of 20–30 feet, in the zone where most sediment movement occurs.

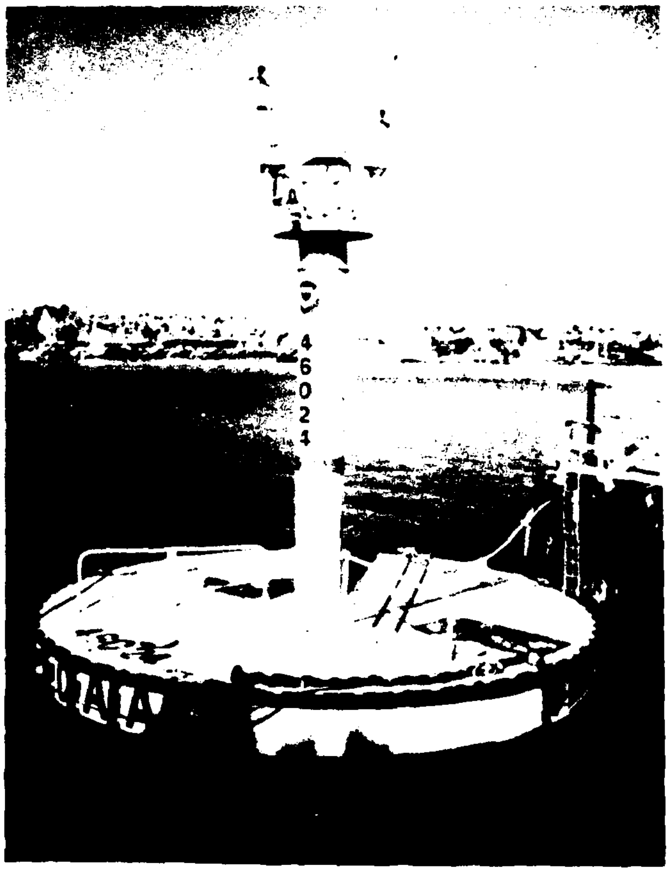
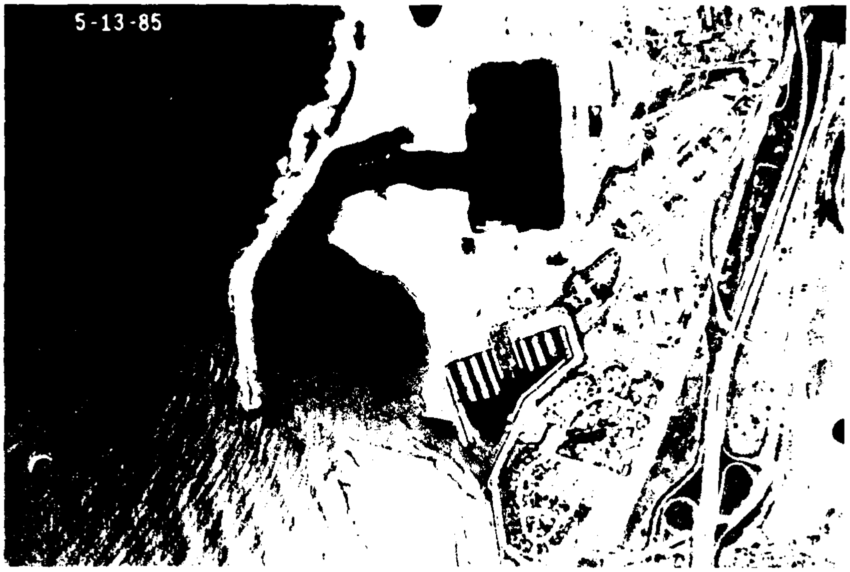


Figure 5. Field Data Collection in the San Diego Region: The NOAA-CCSTWS Directional Buoy which was deployed at the Tanner Banks. In 1985, this buoy provided continuous streams of data about the deepwater wave conditions off the San Diego Coastline. These data can be compared to data from nearshore wave gauges to estimate the effects of islands and nearshore bathymetry on deepwater waves.

(a)



(b)

Figure 6 (a and b): Field Data Collection in the San Diego Region: Aerial Photography at the Oceanside Pier. Photographs, such as those above, taken at various intervals during the year, have revealed changes in the amount of sediment on the beaches.

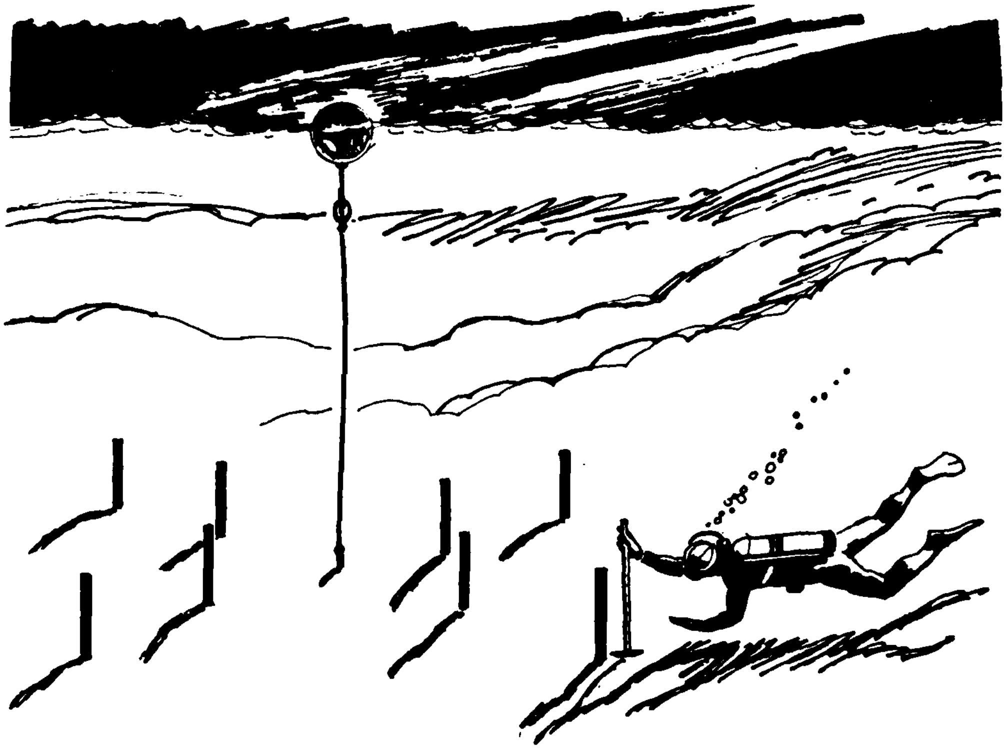


Figure 7. Field Data Collection in the San Diego Region: Offshore Sedimentation Rod Surveys. Brass rods have been driven into the ocean floor at depths of from -45 to -60 feet at several locations along the coast. These rods are checked to determine sediment build up at these depths. Results will show the magnitude of offshore loss of sediments in this region.

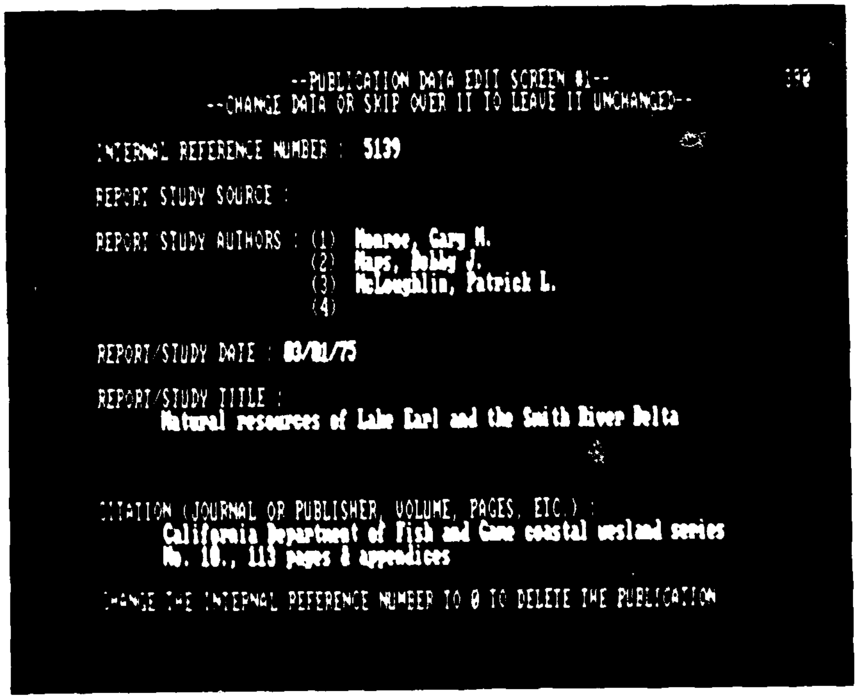


Figure 8. Bibliographic Entry from the 1985 CCSTWS Annotated Bibliography. The annotated bibliography has been computerized, as this sample display illustrates. This will make it easier for researchers to access this important resource.

(a)

(b)

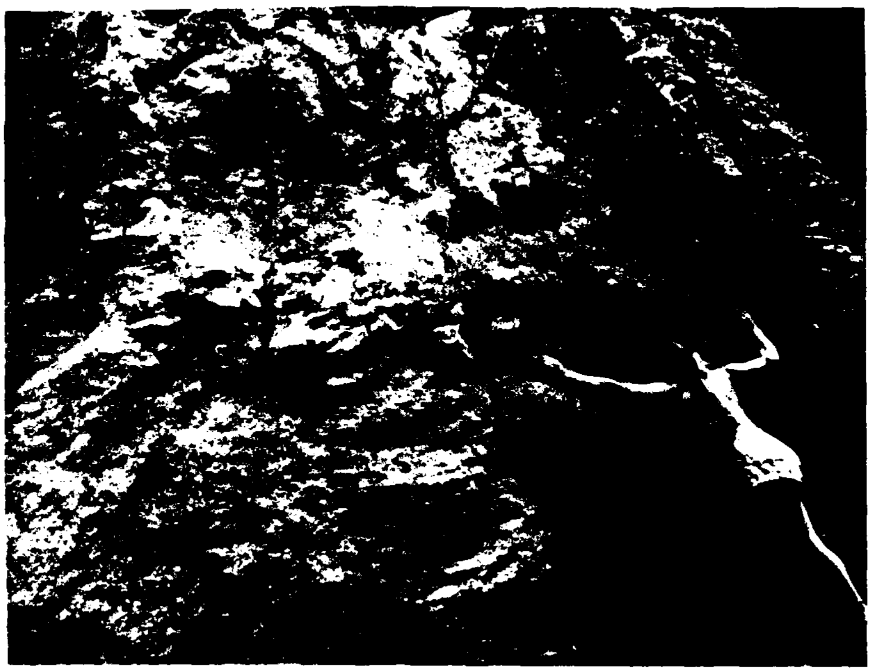


Figure 9 (a and b): Field Data Collection in the San Diego Region: Coastal Cliffs Study. Geologists (above) taking field measurements of cliffs and collecting rock samples will determine coastal cliff erosion rates for various areas along the coast. This will help determine the contribution cliff erosion makes to beach sediments.

(a)

(b)

Figure 10 (a and b): Eroded beach at Oceanside following tne winter storms of February 1986. Understanding the processes involved in such erosion is a major goal of CCSTWS.

CCSTWS FEATURE STUDY, 1985

The Submarine Canyon Study, San Diego Region

In this Annual Report, we are initiating a "Feature Study" section. In this section, we will describe one of the CCSTWS field studies, covering the study in more depth and from a broader perspective than in the technical progress summaries. The Featured Study is intended to give a deeper look into CCSTWS activities.

Submarine Canyons and Beach Sediment Loss

When sediments moving along the coast are carried into the head of a submarine canyon, they accumulate until currents carry them into and beyond the deepwater portions of the canyon (Figure 11). Once in the canyon, they are lost as a resource for beaches.

The quantity of sediment lost to submarine canyons has been estimated, but not measured directly. Estimates vary considerably. It is important to know how much sediment is lost to these canyons, and how the sediment moves into them, in order to (1) determine how important submarine canyons are to the stability of the beaches, and (2) to determine if anything should (and can) be done to prevent these losses.

The submarine canyon study is currently focused on Scripps and La Jolla Submarine Canyons in the San Diego Region (Figure 12). Scripps Canyon extends to within about 660 feet of the shoreline, and the La Jolla Canyon extends to within about 1,000 feet. Both, with canyon heads in about 60-80 feet of water, intercept sediments near the south or downcoast end of the Oceanside Littoral Cell. There have been various estimates of the losses to these two submarine canyons, but no systematic program of measurement.

Scripps and La Jolla Submarine Canyons

The Scripps Submarine Canyon has four branches which reach to within 660 feet of the beach just north of La Jolla Shore (Figure 13). Prior to this study, only three branches had been observed, North Branch, Sumner Branch, and South Branch. A fourth, named Shepard Branch after F.P. Shepard of Scripps Institution of Oceanography, was identified during early CCSTWS study. These four branches are narrow, steep-walled, and deep. From the heads of the branches, the canyon falls off rapidly, reaching a depth of over 660 feet within a distance of about 1,900 feet. About a mile south, La Jolla Submarine Canyon begins as a crescent-shaped bowl about 3,000 feet wide. The rim is cliff-like or scarped, with a sheer vertical drop of up to 33 feet. From the base of the scarp, the canyon then slopes off quickly, reaching a depth of about 400 feet within 1,900 feet from the head. Both Scripps and La Jolla canyons join several miles offshore.

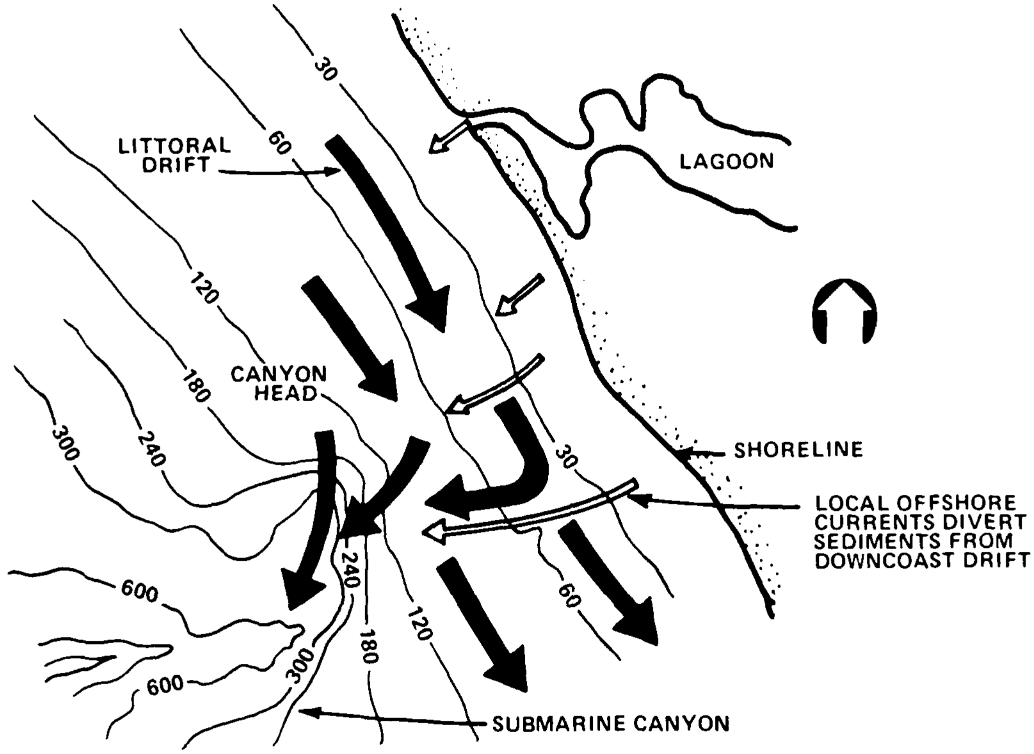


Figure 11. Submarine canyon intercept of littoral sediments moving along the shoreline. Some sediments simply cross the line of the canyon and settle into the canyon head. Others are washed from the beach into the canyon by rip currents.

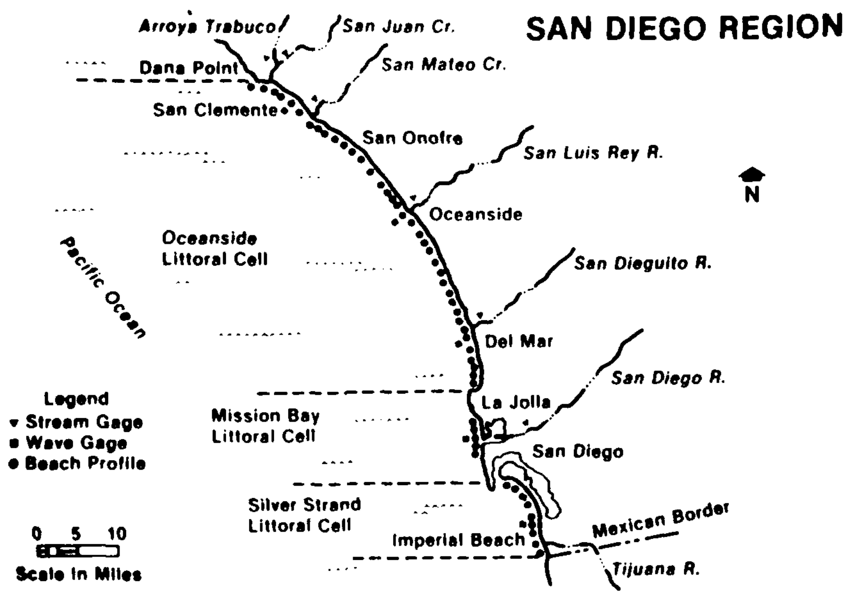


Figure 12. The San Diego Region, site of the submarine canyon study.

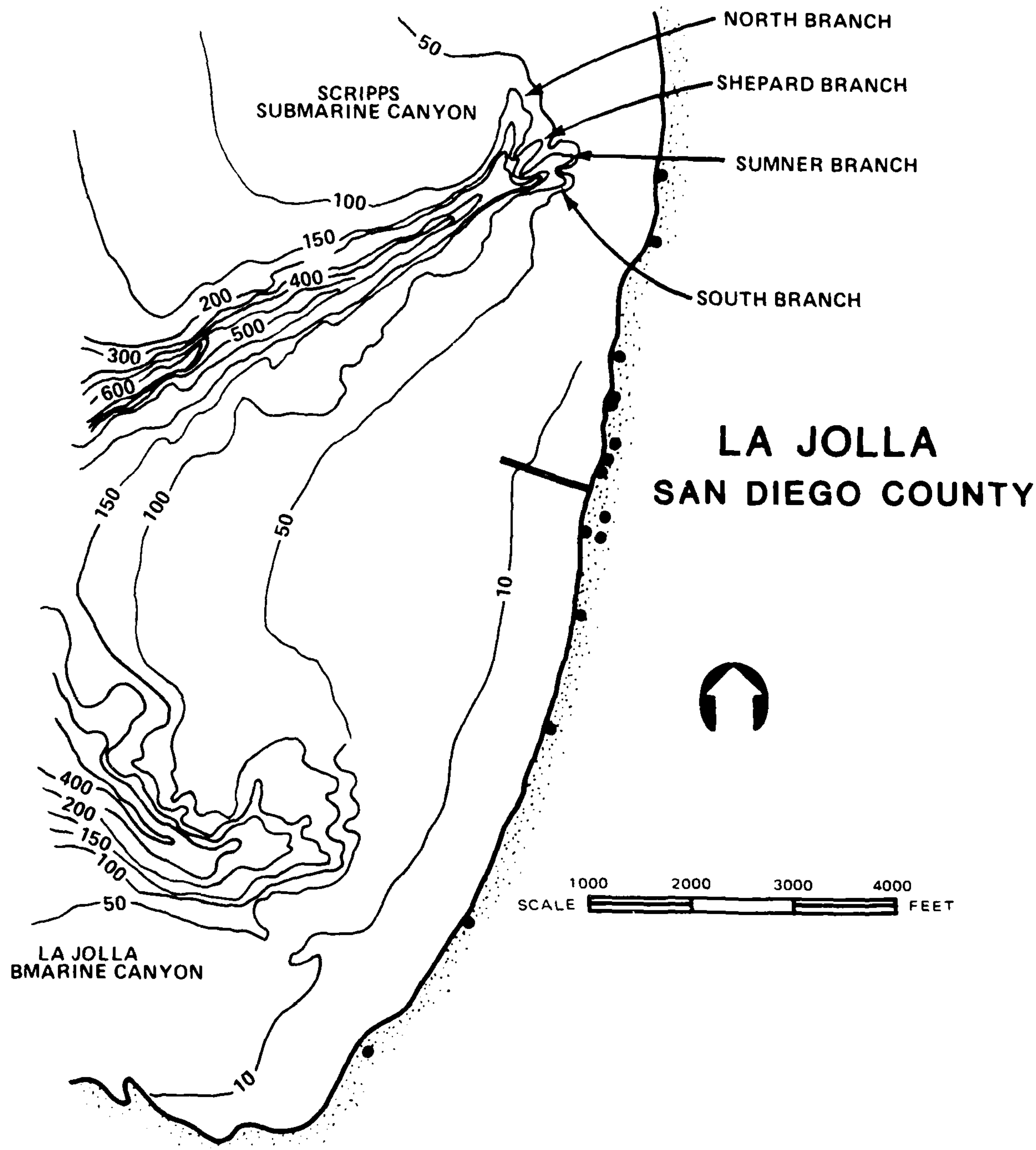


Figure 13. The Scripps and La Jolla Submarine Canyons. The newly-discovered Shepard Canyon branch is indicated by an arrow.

The CCSTWS Study Team

The study is being conducted by the firm of Moffatt and Nichol, Engineers, under a CCSTWS contract. Headed by Dr. Craig Everts and Dr. Robert Dill, the 7-man team of scientist-divers is taking weekly measurements of sediment buildup in the canyon heads and of sediment movement. Assisting the lead researchers is a five-man dive team: Tony Jones (marine biologist), Kevin Kelly (a graduate student in marine geology), Tom Lorensen (marine geologist, Scripps Institution of Oceanography), Tom Judy (San Diego State University), and Dick Wilkins (oceanographer/diver).

Field Study

The main objective of the Submarine Canyon Study is to determine how much littoral sediment is lost to each canyon. Measurements are made with rods driven into the bottom and by measuring changes in depth from submerged reference lines. In addition, sediment traps are fastened to canyon walls near the rim to measure infilling rates. Sediment traps may be either plastic buckets or cloth traps set at different heights above the ocean floor (Figure 14).

Dives are made once a week, with a five-man team making a total of 5 team dives during the dive day. Dives are made in two-man teams for safety. The day begins at about 8:30, when team members meet at Mission Bay, south of La Jolla. Once equipment is aboard the team's 17-foot Boston Whaler, the team heads for the study area. When dive locations are reached, the team evaluates the conditions and determines where it is best to dive, based on the study schedule. During the winter conditions can be rough, both on the surface and in the canyons below. On some occasions, currents and wave surge in the canyon heads have been strong enough to force the divers to spend most of the dive time just trying to hang onto the canyon walls. Visibilities range from a few inches to 50 feet and more (during the late summer). When the sea is rough or visibilities are low, dives are made in those locations where the most can be accomplished given existing conditions.

The boat carries 4 of the team members to the dive locations, and they make the morning dives. Then the boat heads towards Scripps Pier (Figure 13). Tom Lorensen joins the team there, swimming out to the boat for the afternoon dives. Diving is usually over by 2:30, and the team heads home.

Dive activities are carried out to maximize the useful time on the bottom. Team members check rods for evidence of sediment movement and buildup, systematically survey the sediment traps at the rim of the canyons, and measure the distance to the ocean floor from lines strung across the canyons. Changes in the distance from the lines to the floor indicate buildup or erosion of sediment deposits. This program of direct, and frequent, measurement is superior to conventional sounding techniques for several reasons. First, sounding devices can be fooled. Masses of kelp and sea grass, which the dive team finds frequently in the canyon heads, can be mistaken for the ocean floor, giving the impression of greater sediment build up than actually occurs. Second, the weekly dive survey allows the team to compare bottom conditions to local wind and wave conditions. Third, the measurements are more precise than can be achieved through soundings or fathometer surveys. Rods give readings to within about $\frac{1}{2}$-inch, and sediment traps are very precise

Figure 14. Sediment traps at the head of a submarine canyon. Such traps give relatively precise measurement of the flow of sediment into the canyon head, and allow researchers to study the type of sediments moving into the canyons.

indicators of sediment flow rate over the canyon rims. The diving program is thus giving researchers a more accurate view of how sediments build up and are lost in submarine canyons. Instead of yearly estimates with errors measured in the thousands of cubic yards of sediment, the direct measurement program is giving results to the nearest 11 cubic yards.

In human terms, the diving is interesting as well. Working conditions are far from ideal in the canyon heads. Visibilities are often so low that tools placed aside for a moment are never found again. The bathymetry around some of the heads concentrates rip currents, making it difficult to take measurements. Under these conditions, the dive team has developed a close personal and working relationship. The team also shares a sense of the importance of this study, which is the first of its kind.

What Has Been Learned

The study began in 1984, and has been underway for a year and a half. With this limited span of time, it is difficult to draw long-term conclusions about the influence of submarine canyons on the beach. Nevertheless, the research team has made some interesting preliminary observations:

1. Previous estimates of sediment loss into these two canyons appear to be high. Direct measurement during 1985 suggests an annual loss of about 52,000 yds^3/yr, compared to a previous estimate of about 260,000 yds^3/yr.

2. Scripps Canyon, upcoast of La Jolla Canyon and extending closer to the shoreline, appears to receive the majority of the sediment moving downcoast in the Oceanside Littoral Cell.

3. Large quantities of kelp and sea grass move into the canyons throughout the year. This may partially account for high previous estimates of sediment movement, based on sounding methods which could confuse kelp and sea grass with sediment.

4. The buildup of sediment in the canyons is seasonal and episodic, occurring most during fall and winter storms. In December 1984, a winter storm completely flushed several of the branches of Scripps Canyon, leaving nothing but bedrock. The canyons have filled in at an irregular rate since this event.

5. The rim of La Jolla Canyon is retreating towards the shoreline at a rate of 1-2 feet per year. The rim is composed of sedimentary soils which fracture and break off in blocks relatively easily.

6. Sediment losses to Scripps and La Jolla Submarine Canyons are only 5 to 15 percent of the estimated total loss to the Oceanside Littoral Cell's beaches during 1985. The canyons were thus only minor sinks for this sediment during that portion of the study period.

These conclusions should not be interpreted as being definitive. They are valid only for the conditions of the 1.5 year study period to date. Nevertheless, they suggest that we may know less about the role of submarine canyons in the loss

of littoral sediments than previously thought. What has been observed is a relatively irregular buildup of sediment over a period of time, and then a dramatic flushing of that sediment from the canyons to deep water during periods of high storm waves and rip currents.

Future Work

Both of the investigators responsible for the study feel that it has been valuable both scientifically and practically. From a scientific standpoint, the data collected are more accurate and reliable than any collected before. The opportunity for direct measurements has given us a better idea of how important submarine canyons are to the budget of beach sediments, and a better idea of how the sediments are moved into and then flushed out of the canyon heads. From a practical standpoint, the study has given engineers and other researchers a base of data which can be used as a starting point for future study. This study could both lead to a quantitative model of submarine canyon processes and to an evaluation of the feasibility of techniques for reducing losses to submarine canyons. The knowledge gained from this submarine canyon study may thus be the starting point for efforts to reduce losses of beach sediment along the coast of California.

A SUMMARY OF PROGRESS IN 1985

In 1985, the data stream from the San Diego Region continued to provide new insights into coastal processes. The extensive review of literature has also led to some synthesis of fragmented data into an overview of coastal processes along the entire California coastline. Work in 1985 was valuable both for these insights and for the identification of gaps in our current knowledge.

New Knowledge: Sediment Sampling in the San Diego Region

The mineral composition and size of sediments on beaches and in the littoral zone need to be studied so that beach sediment movement can be monitored and sediment origins can be traced to various sediment sources such as rivers and cliffs. Changes in sediment characteristics may indicate changes in the direction and magnitude of littoral drift, or a change in the dominant source of sediment for the beaches.

In the past, sediment samples have been taken at many random points along the coast. The CCSTWS survey, however, was a systematic sampling effort, designed to identify trends in mineral composition and sediment particle size along the entire coastline of the San Diego Region. Samples were collected at numerous locations during both winter and summer seasons. Data from the sampling program were compared to data from previous studies.

The result of this study is that we now know more about the distribution of sediments in the littoral zone than ever before (Figure 15). It is now possible to divide the region's beaches into distinct zones on the basis of sediment mineral composition and grain size. Using this information about the size and mineral characteristics of sediments along the coast, some initial conclusions have been made about the sources and movement of beach sediments:

1. Sediment grain sizes in the littoral zone remain relatively constant from winter to summer,

2. While downcoast littoral drift is dominant, the drift patterns are complex, with considerable seasonal variation in littoral movement in many areas,

3. Samples appear to vary with wave conditions, and thus samples at a given location must be taken in a short period of time.

A full description of these results is found in CCSTWS Publication 85-11, "LITTORAL ZONE SEDIMENTS, SAN DIEGO REGION, October 1983-June 1984."

New Knowledge: Historical Shoreline Movement in Southern California

Historical records from aerial photography and ground survey efforts are useful for identifying long-term trends. In addition, records of changes in the shoreline (erosion, accretion) may help in analysis of the effects of storms or human influence on the coast (dams, roads, harbors). In studying the records for a 130-year period, researchers looked for correlations between changes in the shoreline and various causal factors. The study resulted in graphs of erosion and accretion for a variety of points along the southern California coastline (Figure 16). These graphs are

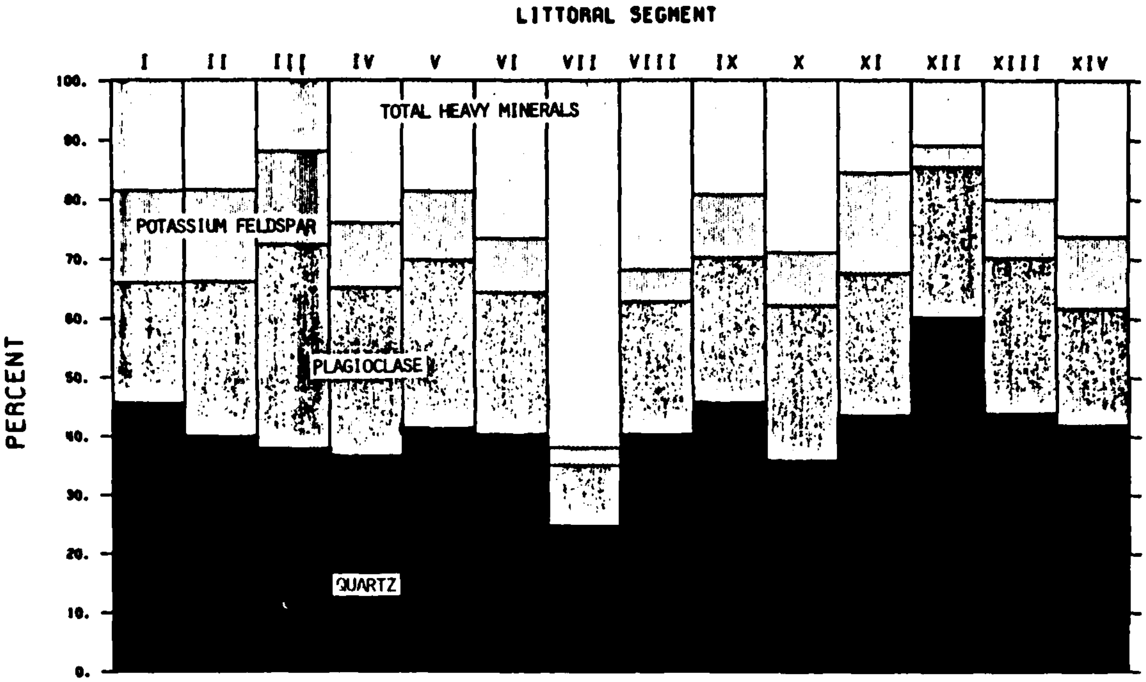


Figure 15. Average mineral composition of sediment samples by littoral segment San Diego Region, end of winter data set.

Segment	Location
I	Dana Point Harbor to north of San Mateo Creek
II	San Mateo Creek to Las Flores Creek
III	French Canyon
IV	Between Santa Margarita River and Oceanside Harbor
V	Oceanside Pier to south of Agua Hedionda Lagoon
VI	Batiquitos Lagoon
VII	San Elijo Lagoon
VIII	San Dieguito River
IX	South of Solidad Valley, near Torrey Pines
X	South end of Torrey Pines, north of La Jolla
XI	Mission Bay, north of bay entrance
XII	Between San Diego River and San Diego Harbor
XIII	Silver Strand Beach
XIV	At the U.S-Mexico Border

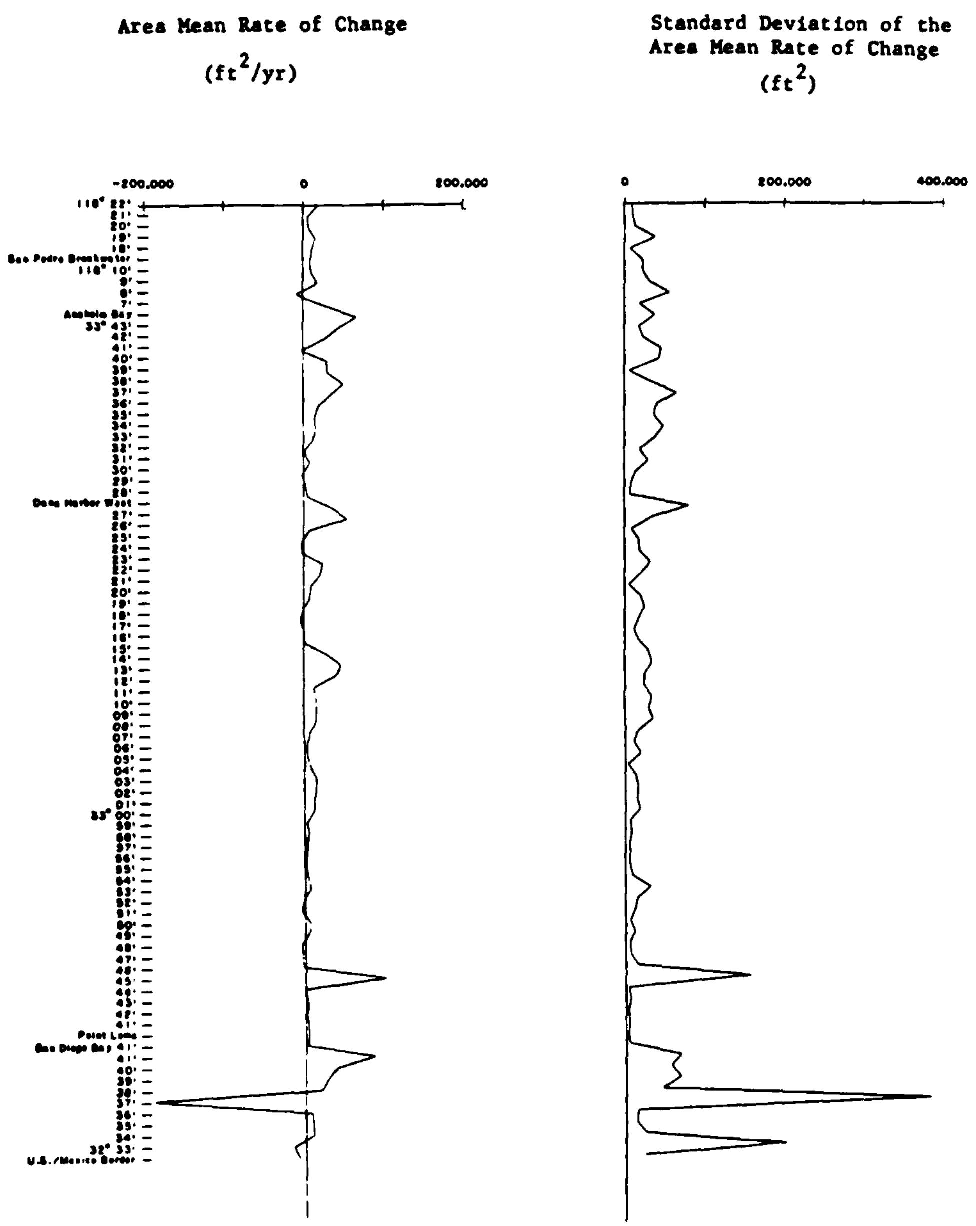


Figure 16. Shoreline area mean rate of change and standard deviation, from north of San Pedro to the Mexican Border (1852 - 1982).

intended to reveal any consistent long-term patterns. Most of the graphs developed showed a general trend towards accretion (beach build up which extends the shoreline into the ocean), but there was considerable deviation for many locations, indicating a tendency for the shoreline to advance and then retreat and then advance again. In addition, as can be seen from Figure 16, the changes recorded over the last 130 years are extremely local, with areas only a few miles apart differing substantially. In the San Diego area, for example, there was substantial accretion in the San Diego Bay beaches, and massive erosion just to the south.

In 1985, analysis of data from the historic shoreline mapping and survey efforts was completed. The overall conclusion to be drawn from this systematic review was that the coastline is complex, with no overall trend indicated by the data. Human development, storms, normal variation in wave action, changes in the watershed, and cycles of weather may all be interacting to produce this complex picture of the coastline. Predictions of future shoreline movement must thus be made on a local basis. Even with a record of almost 130 years, long-term, regional-scale trends are not evident in the data. Predictions of shoreline change will thus depend on an understanding of local coastal processes.

The shoreline movement study (CCSTWS Publication 85-10) is significant because it demonstrates that there are no easy approaches to predicting shoreline change. Local wind, wave, tide, and precipitation patterns seem to dominate. This finding reinforces the need for the detailed analysis of the coastline, by littoral cell, which is the goal of CCSTWS.

New Knowledge: Nearshore Bathymetric Surveys

Very precise measurement of nearshore bathymetry is necessary to estimate the volume of sediment on the beaches. These volume measurements make it possible to trace the movement of sediment on and off shore, and along shore. In 1985, initial bathymetric surveys, conducted using an hydrostatic profiler, were compiled (CCSTWS Publication 85-3). Profiles were taken during both winter and summer periods.

A review of these data reveals that the summer-winter profile for most beaches changes as expected, with erosion of beaches during winter (deposition on an offshore bar) and accretion during summer months (Figure 17). The pattern is not uniform, however. In some areas, the summer-winter pattern is very complex, with numerous bars and areas of erosion evident from the summer-winter profiles (Figure 18). This suggests that local wave and bathymetric conditions can act in concert to create very complex bathymetry. The complexity evident in some profiles is an indication of the difficulties facing researchers in attempts to develop mathematical models of coastal processes. For some locations, onshore and offshore movement of sediments will prove quite difficult to predict. Continued profiling, which may help explain some of the anomalies discovered in the initial profiling effort, is essential.

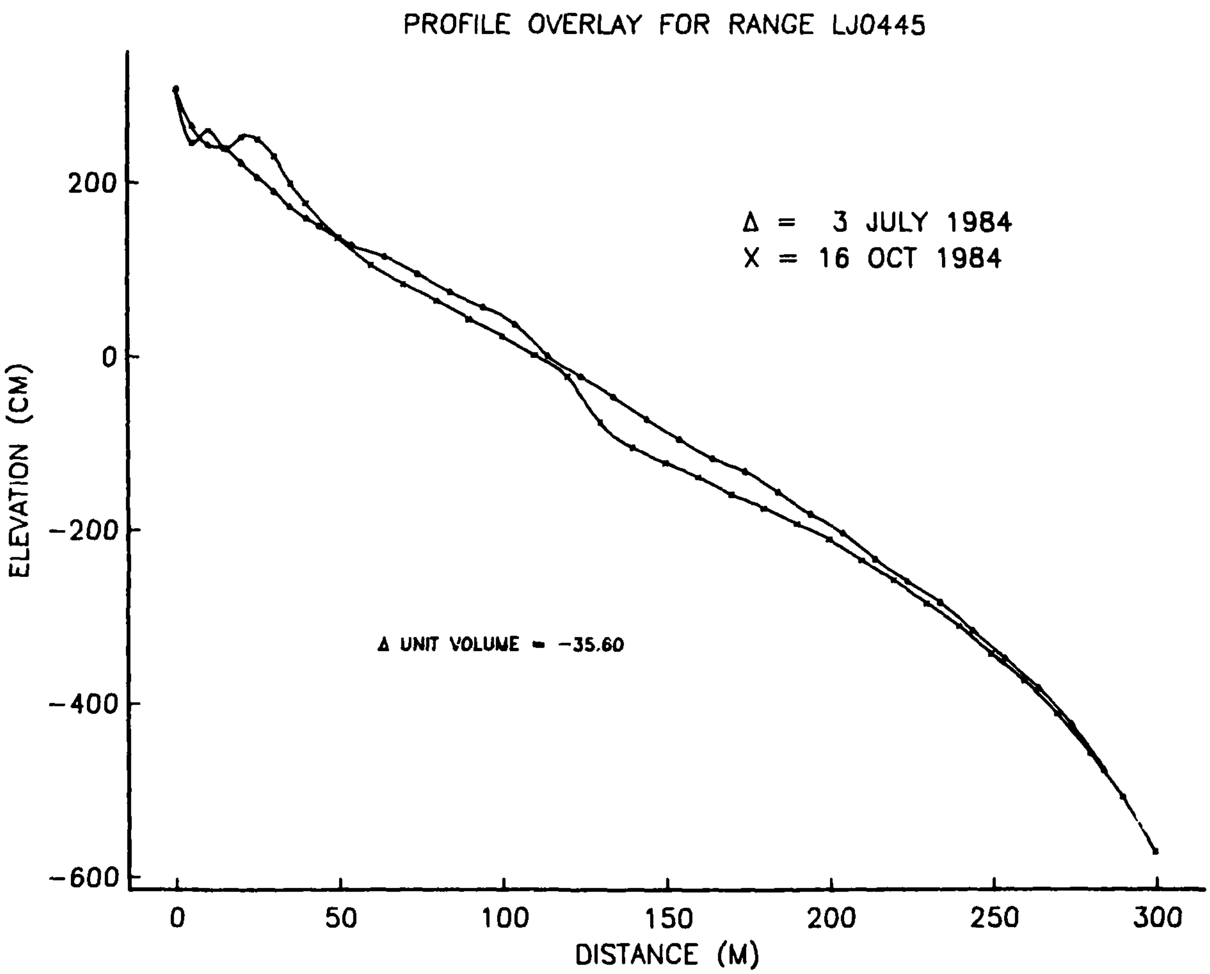


Figure 17. Typical winter-summer beach profile from the initial survey in the San Diego Region. Note the movement of sediment to an offshore bar during winter storms.

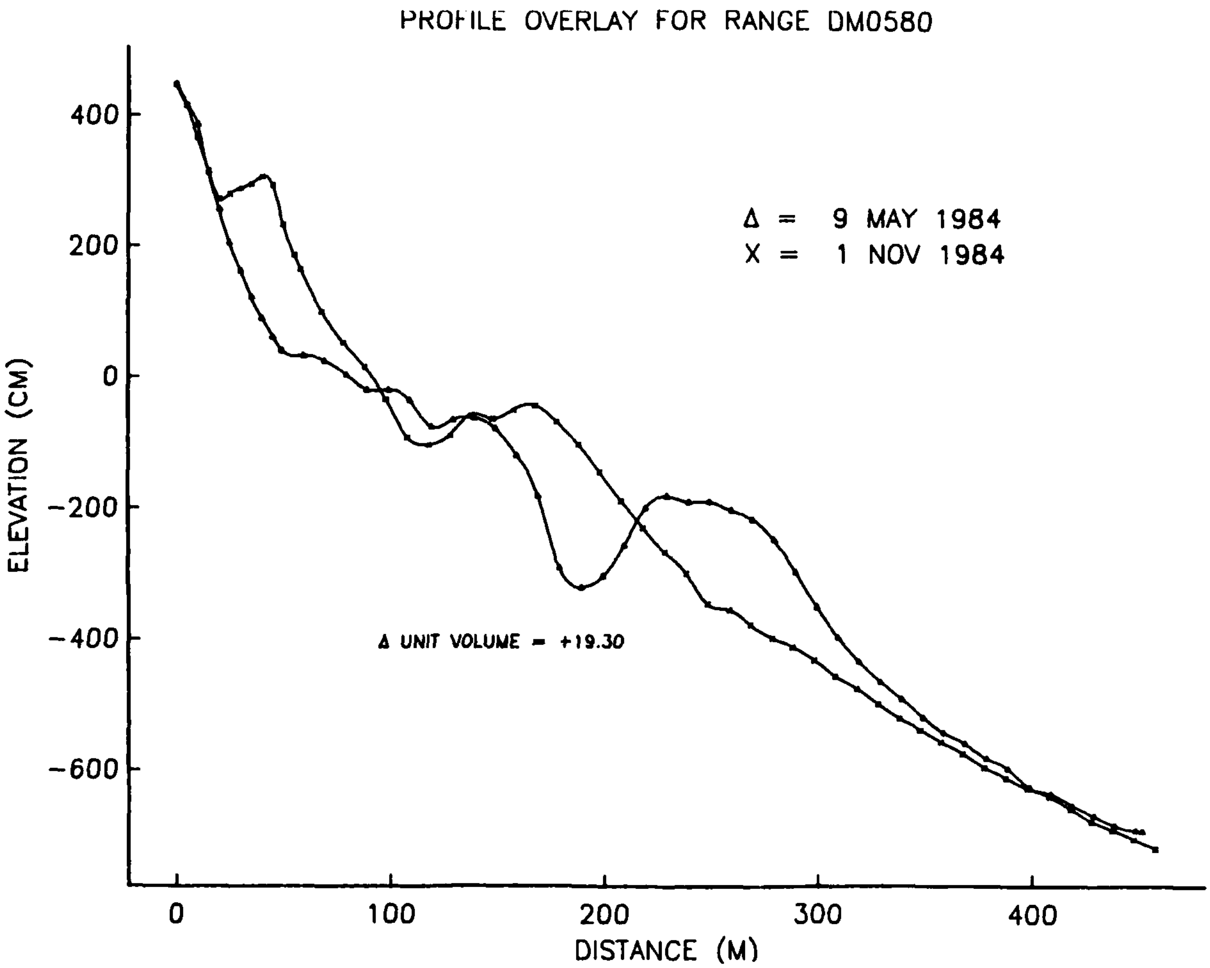


Figure 18. Winter-summer beach profiles for range line DM0580 (Del Mar). Note the complexity of this profile when compared to the profile in Figure 17.

Review of Literature: Geotechnical Data Inventory

As a part of the planning process, geotechnical data in current literature were reviewed, the results summarized in CCSTWS Publication 85-5, "GEOTECHNICAL DATA INVENTORY, SOUTHERN CALIFORNIA." This review covered:

* Physical properties of sediments
* Presence of landslides in regional drainage basins
* Drainage basin productivity
* Cliff erosion rates
* Dune fields
* Major geologic features related to littoral processes, such as submarine canyons.

This review confirms the geologic complexity of the southern California area (the Mexican Border to Ragged Point in San Luis Obispo County). The implication of this complexity is that regional conclusions about geology and its impact on littoral processes are not possible. Study of local conditions, on a cell-by-cell basis, is necessary for development of quantitative analysis. Some of the complexity of the region is indicated by the summary table of geologic findings (Table 2).

In addition to the findings summarized in Table 2, the review revealed that data are most readily available in or around urban areas, partly because flood control projects and shore protection projects in these areas have required previous geologic investigation. Thus the data base for CCSTWS is quite extensive for some sections of the coastline, and very limited for others. This is reflected in plans of study for the regions, which call for comprehensive data collection activities. Detailed quantitative studies are needed because a systematic review of sediment sources for each littoral cell's beaches has not been performed.

The review also demonstrated that the sediment characteristics for the region vary significantly from littoral cell to littoral cell, and even within cells. The Oceanside Cell was found to contain seven distinct mineral provinces (based on sediment mineral composition), and grain size was seen to vary with distance from presumed sediment sources. The differences in sediment characteristics for each cell reinforces the emphasis of CCSTWS on the littoral cell as the primary unit of study. Different assemblages of sediments from cell to cell indicate that each cell has substantial independence and that there is little littoral transport from cell to cell.

The complexity of the coastline was also confirmed by the review of seismic activity. Some areas show high activity and others show little major activity. There are areas of emergence and subsidence, often several within a single littoral cell, as in the Oceanside Cell. This indicates that major geologic forces are affecting the configuration of the shoreline, albeit slowly at present. Emergence and/or subsidence rates in the literature ranged from 0.2 inches/50 years to as high as 1.5 feet/50 years. There was little information for the more remote littoral cells.

Table 2. Selected *geologic findings* from review of existing literature for the southern California area (Ragged Point to the Mexican Border), by littoral cell (Morro Bay Cell = 1, Santa Maria River Cell = 2, Santa Ynez River Cell = 3, Santa Barbara Cell = 4, Santa Monica Cell = 5, San Pedro Cell = 6, Oceanside Cell = 7, Mission Bay Cell = 8, and Silver Strand Cell = 9).

Characteristic	Cell Number								
	1	2	3	4	5	6	7	8	9
Shoreline Composition									
Dunes (%)	25	100	70	10	20	0	1	0	15
Cliffs (%)	50	0	30	0	0	30	95	60	0
Cliffs/Beaches (%)	25	0	0	90	80	70	4	40	85
Active Submarine Canyons Present?	UNK	UNK	NO	YES	YES	YES	YES	NO	YES?
Nearshore Morphology									
Rocky (%)	80	10	20	30	40	15	50	60	0
Sandy (%)	20	90	80	70	60	85	50	40	100
Estimated Annual Sediment Production of Drainage Basin (1,000's cu.yds/yr)	UNK	UNK	UNK	5,700	340	4,400	2,860	380	2,100
Active Slides in Cell? (% area highly active)	10	0	0	50	10	25	10	5	5

UNK = unknown at this time.

Review of Literature: Meteorological Data Inventory, Southern California Coastal Zone

There is a vast record of meteorological data available to researchers, but little of it is in readily useable or in summary form. In addition, much of the data collection has been at sites of convenience (city halls, airports) rather than sites selected for their scientific value. Thus there are very detailed records of precipitation in urban watersheds, and very sketchy information for watersheds which do not include a major urban area. Meteorologic records for offshore locations are perhaps less systematic and reliable, having been collected primarily within shipping lanes. Data collection at sea has been haphazard as well, depending primarily on the care and effort of individual navigators. The general weather data for offshore areas is thus reasonably sound, but data about local effects is not adequate to permit weather patterns to be characterized in detail. Data on offshore conditions during major storms is particularly anecdotal, as systematic measurement of wind and waves is difficult during such life-threatening events, and observations may be colored by the emotions of the observer.

Despite these data limitations, the survey of available meteorological data proved useful for CCSTWS planning in a number of ways. General patterns of weather were clarified, both long-term cycles and annual weather patterns. Wind and precipitation data for onshore sites were detailed enough to identify sites where heavy erosion would be likely to occur. The study thus provides an adequate initial data base for study of the influence of meteorological conditions on California's beaches.

The entire region, from Ragged Point in San Luis Obispo County to the Mexican Border was shown to be subject to the same general storm patterns. Winter storms approach from either the northwest (from the Gulf of Alaska) or, depending on the positioning of the Pacific High Pressure Zone, from due west (from the Hawaiian region). The northern portions of southern California receive a greater proportion of rainfall from storms from the north, while storms from the west may distribute rainfall evenly throughout the region. In summer and fall, normally dry periods for the entire region, moist tropical air masses may move north, bringing local thunderstorms in the mountains and, rarely, general rainfall to the region. Tropical cyclones are rare, but have reached as far north as Los Angeles, bringing heavy rainfall.

The location of the Pacific High is the critical variable in weather prediction in this region. When, as is normal, the high centers over the southern Sierra Nevada, storms approach from the north and precipitation is higher in northern areas. When the Pacific High moves further south, and the jet stream drops south as well, the southern portion of the region may receive the heaviest rainfall and winds.

Throughout the region, precipitation data reveal the complexity of the weather patterns. Local topography has a major effect on precipitation. Mean annual rainfall can vary substantially in locations within several miles of each other,

and the range of maximum and minimum rainfall is often extreme, for example 61.7 inches to 10.0 inches at Palomar, near San Diego. Precipitation within a single watershed may vary substantially; different portions of the watershed may

thus contribute more to the sediment load of the watershed's rivers and streams than others.

Wind patterns also were found to be complex and highly influenced by local conditions. Wind velocities vary considerably from point to point in the region, with high winds in the inland mountain passes. Wind patterns during the hot, dry foehn wind conditions of the fall and early winter illustrate the complexity of the conditions in the region. These winds occur when there is a general high pressure build up over the inland deserts. Local topography affects their path and velocity to such an extent that in some locations there is an onshore breeze associated with the general offshore flow.

In general, a review of meteorological conditions in southern California reinforces the CCSTWS focus on the littoral cell as the appropriate unit for study. Southern California is a region of microclimates, with great temperature, wind, and precipitation differences found in relative proximity. The storms of 1982-83 are an illustration of this. Where normal precipitation patterns involve increasing rainfall as a storm moves inland and into the mountains, the 1982-83 storms approached from a more southerly direction (associated with the El Nino condition of that period) and rainfall was greatest in the immediate coastal zone, the first 5 miles of coastline.

In sum, this review of meteorologic data demonstrated the complexity of the problem facing CCSTWS modeling efforts, and the variability in conditions which must be taken into account in any effort to model the influence of meteorological conditions on the region's beaches.

Review of Literature: Geomorphology Framework Report for Monterey Bay

Monterey Bay (Figure 19) is a high CCSTWS priority for several reasons. First, it is heavily developed at both the north and south ends (Santa Cruz and Monterey, respectively). Second, there have been damages from recent storms, indicating that the area needs to be studied. Third, the area has been studied extensively in the past. Many of the data needed for a model of littoral processes are available.

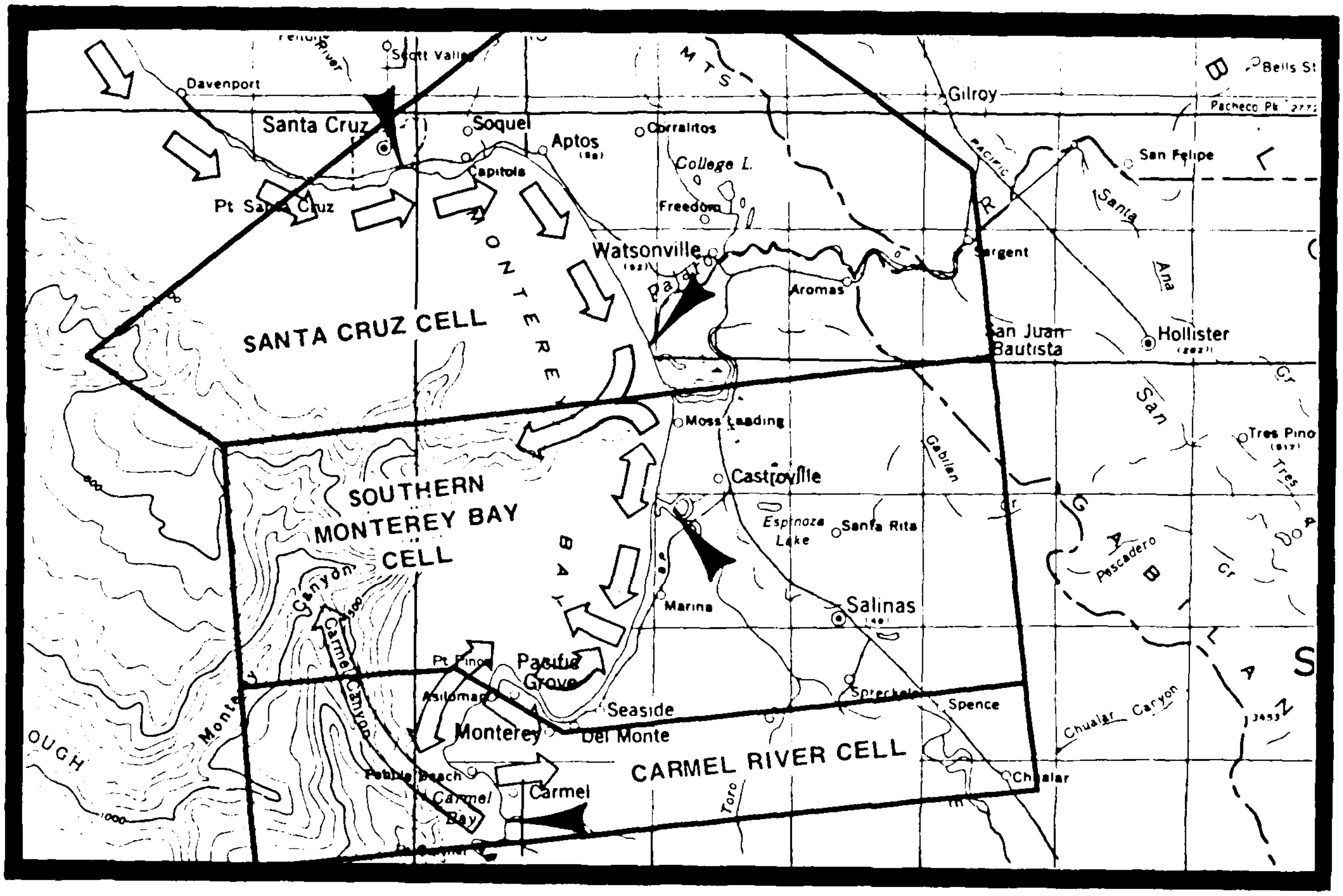


Figure 19. Monterey Bay and its three littoral cells.

A geotechnical review is essential prior to development of a detailed plan of field study. Geotechnical field work is expensive and must be planned for maximum efficiency. A thorough review of existing literature was thus undertaken.

The review of literature concerning Monterey Bay was extensive. Data were found which led to characterization of sediment zones in the Bay. Five minerological provinces were identified (Table 3). Historical records of bluff retreat show substantial change in cliff formations along the shoreline from 1940 to 1978, and cliff erosion rates have been calculated for the entire bay area. The sediment characteristics of the bay and its sediment sources are relatively well defined. Wind forces were found to be relatively well-documented, thus making it possible to analyze the amount of sand movement on and off shore due to winds. Finally, the basin's sediment resources were found to be relatively well characterized.

Table 3. Five provinces of heavy minerals in the Monterey Bay area (from Yancey, 1968).

Heavy Mineral	Province - Percent Composition				
	1	2	3	4	5
Green hornblende	48.6	54.0	45.1	40.7	28.0
Brown hornblende	10.7	5.0	4.7	4.0	3.7
Oxyhornblende	1.7	1.9	3.6	4.4	2.0
Augite	16.7	16.6	22.5	26.1	40.1
Hypersthene	2.9	6.0	9.0	12.5	15.2
Epidote	2.2	4.6	5.5	4.9	5.7
Garnet	10.9	3.6	2.0	1.4	2.0
Sphene	3.3	4.0	2.9	2.4	1.7
Zircon	1.3	1.0	0.5	0.9	0.4
Apatite	1.2	3.1	1.5	1.0	0.1
Clinozoisite	0.1	0.3	0.4	0.5	0.4
Detrital carbonate	0.2		0.1	0.4	0.1
Glaucophane		0.3	1.6	0.6	0.1
Lawsonite		0.5	0.1		
Tourmaline		0.1		0.1	
Staurolite	0.1				

Provinces:

I: Beaches and nearshore area off the mouth of the Salinas River
II: Offshore area west of Province I
III: Northeastern portion of the Monterey Bay
IV: North of Province III, extending to the bay's north shore
V: Point Santa Cruz north

On the basis of these findings, it was possible to describe the factors affecting beach conditions in Monterey Bay in at least general terms. The most important sediment sources were determined to be:

* Longshore transport into the area
* River transport
* Sea cliff erosion

The most important sediment sinks in the area were determined to be:

* The Monterey Submarine Canyon
* Sand and gravel mining

In addition, onshore waves were determined to be locally important to beaches, while wind transport from dunes to beach, hydrogenous deposition, beach nourishment projects, and biogenous deposition were found to be minor sediment sources. Sinks of local importance were offshore transport by waves and currents and wind transport from beach to dunes. Longshore transport out of the area and solution and abrasion were not determined to have any substantial influence.

The problems facing Monterey Bay were also well documented in the literature. Beaches are eroding under current conditions, threatening numerous areas of human development. The Bay is not in an equilibrium state, and immediate shore protection efforts may be needed to stabilize the shoreline.

While the data available were found to be quite useful to CCSTWS, some weaknesses were found for which field work will be needed. First, the sediment contribution of the cliffs to the north of the bay is currently unknown; it needs to be established in precise quantitative terms before the littoral processes of the bay are understood. Second, the sediment supply rate, highly variable and dependent on major flood flows, needs to be estimated more precisely. Third, the movement of sand in the bay, and the total resource available, needs to be determined. Fourth, onshore transport of sediment needs to be measured. These weaknesses in the available data will be addressed in further geotechnical study of the area. A full review of the geotechnical literature for Monterey Bay is contained in CCSTWS 85-2, GEOMORPHOLOGY FRAMEWORK REPORT MONTEREY BAY.

Review of Literature: Hydraulic Data Inventory, Southern California Coastal Zone

Data about the flow of rivers and streams, and about their sediment loads, is critical to understanding littoral processes. It must be possible to quantify sediment contributions from the major rivers and streams in order to develop a useable sediment budget.

Review of existing literature in this field revealed very little useable information. Only five studies were found to provide reliable data. In these five studies, estimates of mean annual sediment load for some of southern California's rivers and streams

varied widely. The range for some rivers varied by close to an order of magnitude:

Tijuana River:	162,000 to 1,109,100 metric tonnes
San Luis Rey River:	67,700 to 430,000 metric tonnes
Santa Clara River:	181,400 to 3,330,000 metric tonnes

Similar variation in sediment discharge was found for other southern California rivers. These wide differences in estimates are due to differences in estimating technique and the extreme variability in flow statistics for these rivers and streams, most of which have ephemeral flow.

From the hydraulic data inventory, it is clear that there is much work to be done to quantify the riverine sediment sources for the littoral cells of southern California. This work may include field work with sediment gauges on major rivers and streams in the region.

Review of Literature: Hydrologic Data Inventory

It is essential to understand precipitation and runoff patterns in order to determine how much sediment reaches the beaches from inland sources, and how frequently there is substantial sediment flow to the shoreline. There are a number of factors which influence runoff:

* Amount and timing of precipitation
* Watershed stability (soils, vegetation cover)
* Presence of dams and debris basins
* Fires
* Slope of watershed

The hydrologic data inventory addressed all of these factors.

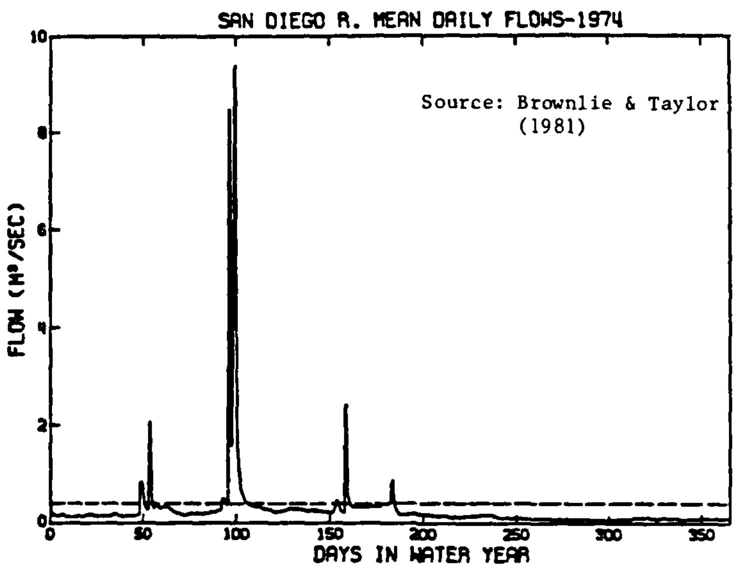
Relatively precise rainfall and runoff records are available for southern California rivers and streams. Much of the information on hydrology in the southern California region is from flood control studies, and there are relatively good data available on flood frequency for all of the region's major rivers and streams. These data are pre-flood control project data, however, and there is frequently little analysis available for post-project conditions. Thus, the influence of dams and debris basins is not well documented. It is possible to estimate the amount of sediment trapped behind flood control and water conservation dams, but these estimates do not give an accurate picture of total flow to the coast. Water running out of dams and debris basins is relatively "clear." Most of the mud and sand it was carrying when it entered the reservoir has settled to the reservoir bottom. The water running from these dams thus has the capacity to pick up a sediment load in downstream areas, somewhat compensating for sediment which settles out behind the dam. Total sediment load for rivers with dams or debris basins is quite difficult to calculate, because the load picked up by clear water running from these structures has not been quantified.

The size and soil characteristics of major watersheds with rivers running through urban areas has been well-documented during flood control and other studies, and the influence of vegetation on runoff is at least qualitatively known. But predictions of events such as mudslides and heavy gullying due to poor vegetative cover are qualitative and quite tenuous.

The influence of fires on runoff and sediment transport is also well known in general terms. Major fires are well-documented in regard to their timing and extent, and there are records of landslides, mudflows, and gullying associated with fires. But there has been no quantitative study of the effects of fire on runoff and sediment transport. Thus it is possible to predict additional runoff from a burned area, but not presently possible to say how much runoff will increase over pre-fire conditions, nor how much sediment will be carried with this additional runoff. A study is now underway to better quantify sediment runoff from burned areas.

Data about sediment "flow" to the coastline in rivers and streams is needed to understand the beach building and erosion process. Precise data are needed so that engineers can predict how much sediment will reach the beaches under a variety of conditions. In recent years, there has been an attempt to begin keeping the needed data. Streamflow records have been synthesized into average annual flow graphs (Figure 20), and riverine sediment characteristics have been explored in some rivers (Figure 21). Water quality monitoring has also increased the understanding of river sediment discharge. Despite this progress, it is still not possible to accurately predict runoff and sediment flow to the beaches on most southern California rivers and streams.

The result of the hydrologic data inventory is a recommendation for more systematic quantitative study of sediment discharges under a variety of conditions. Sediment quantities and sediment characteristics must be established so that numerical models can be developed for use in analyzing engineering projects and for planning to protect a region's beaches. The HYDROLOGIC DATA INVENTORY SOUTHERN CALIFORNIA COASTAL ZONE is available as CCSTWS 85-8.



Typical annual sequence of mean daily flows (1974 water year)

Figure 20. Typical average daily flow for the San Diego River, based on the 1974 water year (USGS).

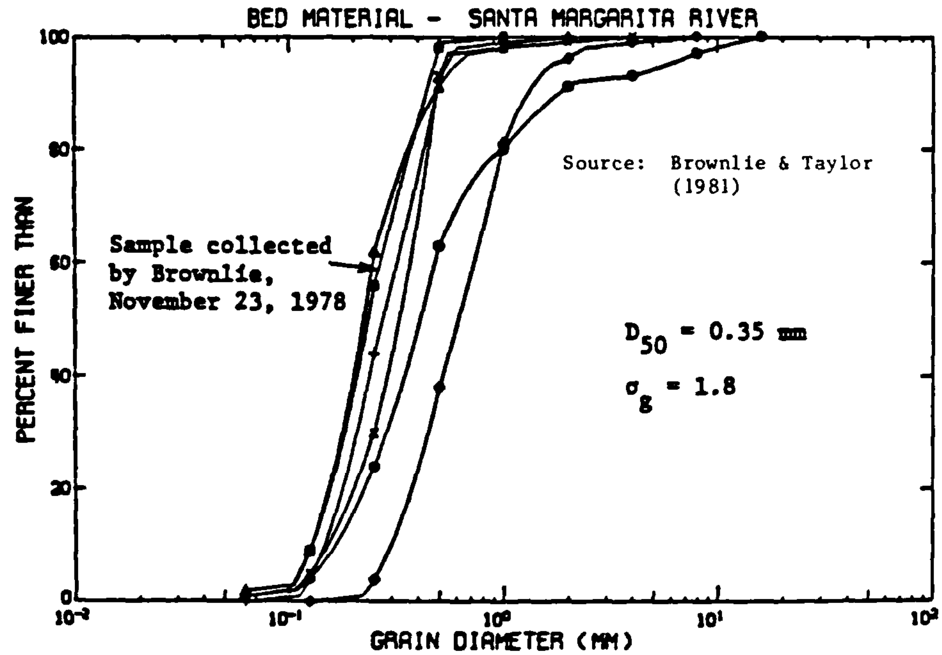


Figure 21. Results of bed-sampling efforts in the Santa Margarita River in San Diego County (composite results) for the period November 27, 1967 to August 16, 1973 and on November 23, 1978. Such analysis is available for some southern California rivers and streams.

Review of Literature: Socioeconomic Data Summary, Southern California Shoreline

Beach and cliff erosion are natural phenomenon which become problems only when they affect human development. When this occurs, it is important to understand the value of the property affected, so that feasibility analyses can be based on realistic economic evaluation. In addition, it is useful to understand the total value of coastal property when dealing with issues such as shore protection measures and planning for harbors and recreational areas.

The CCSTWS review of shoreline socioeconomics was intended to help planners get a realistic view of the development along the shoreline, and of the public and private use of the region's beaches.

The study found that there is no readily accessible data base of this information. Land use and value is generally obtained only through a painful and costly review of records of individual holdings. Thus, without an exhaustive unit-by-unit study, it is impossible to place a precise value on shoreline holdings. Estimates for each littoral cell were made, nevertheless, on the basis of recent transactions. Property within the officially designated coastal zone from Ragged Point in San Luis Obispo County and the Mexican Border was estimated to be worth in excess of $800 billion. Property in the immediate shoreline area, which might be threatened by storm waves and tides may account for as much as one fourth of this value, or $200 billion.

Property ownership and use figures reflect the general public concern for and appreciation of the beaches. Below Point Conception, most beaches are in public ownership (local, state, and Federal parks and recreation areas, and military installations). Public use of these beaches is high, with 118.5 million users in 1984, at public beaches alone. Most of this beach use was by local residents, although tourist visits were high in some areas.

Conversations with local officials revealed a concern that beaches be stabilized, although most officials reported that their beaches had recovered from the erosion caused by the 1982-83 winter storms.

Detailed ownership and use records were available, and are summarized in SOCIOECONOMIC DATA SUMMARY, SOUTHERN CALIFORNIA SHORELINE (CCSTWS 85-6).

Review of Literature: Southern California Coastal Processes Data Summary

Southern California is the site of several major oceanographic research institutes, including Scripps Institution of Oceanography. In addition, there are numerous local, state, and Federal projects along the coast (harbors, shore protection projects). It is not surprising, then, that the region has been relatively intensively studied. The San Diego Region, where Scripps Institution of Oceanography is located, has been particularly well studied. There are preliminary sediment budgets developed for the San Diego Region as a result.

Review of the literature revealed that, despite this study, a data base for development of littoral cell sediment budgets was not available. Much of what is currently known about southern California's shoreline is fragmented and there are major data gaps. Study to date has often focused on understanding the processes affecting the shoreline in a general manner, rather than on precise quantification of the influence of these processes.

The deepwater wave climate has been analyzed by several researchers, and there are wave hindcasts for many areas of the coastline. Recently, for example, the Coastal Data Information Program has placed a number wave measuring devices from Imperial Beach in the south to Diablo Canyon in San Luis Obispo County. Thus, from 1977 to the present, there has been a massive increase in the quantitative data available for almost the entire southern California region, including the seldom-studied area north of Point Conception (Table 4). Many of these wave gauges have been in relatively shallow water, however, and deepwater wave climate is still not known to any degree of precision. The review of literature revealed that there is a need for additional deepwater and nearshore wave measurements, and that these measurements need to be correlated to one another in order to determine how local bathymetry affects waves as they approach the shoreline.

Existing study of some locations has been extensive, however. Wave climate near Scripps Institution of Oceanography has been well documented. Wave height and frequency for waves from both northern and southern hemisphere have been estimated on the basis of detailed wave records. Refraction effects off La Jolla have also been studied, and predicted changes in the height of waves approaching various locations have been correlated to observed changes (Figure 22). In recent years, there have been coordinated efforts to collect data about variables such as daily

Table 4. Coastal Data Information Program Stations, 1977-1984.

Station Name and Location	Type[1]	Depth (feet)	Years in Use
Imperial Beach 32 35.0' N, 117 08.2'W	Array	33.5	77-78 83-84
Ocean Beach	—	—	77-78
Mission Bay, 32 45.4'N; 117 15.7'W	Array	33.0	78-83
Mission Bay, 32 45.9'N; 117 22.5'W	Buoy	550.0	81-83
Scripps Pier, 32 52.0'N; 117 15.4'W	S.P.	26.4	77-84
Del Mar, 32 57.4'N; 117 16.7'W	Array	35.3	83-84
Oceanside, 33 11.4'N; 117 23.4'W	Array	30.3	77-81 83-84
San Clemente, 33 24.9'N; 117 37.8'W	Array	33.6	83-84
Sunset Beach, 33 42.5'N; 118 04.2'W	Array	27.0	80-83
Santa Cruz Is., 33 58.3'N; 119 38.5'W	Buoy	180.8	83-84
San Pedro Chan., 33 35.0'N; 118 14.9'W	Buoy	386.0	81-82
St. Monica Bay, 33 53.0'N; 118 38.0'W	Buoy	391.0	81-82
Pt. Mugu, 34 05.4'N; 119 06.8'W	Buoy	59.4	82-83
Channel Is., 34 10.0'N; 119 14.2'W	S.P.	19.8	77-83
Santa Barbara, 34 24.1'N; 119 41.5'W	Array	29.7	80-83
Point Conception,	Buoy	---	79
Pt. Arguello, 34 40.0'N; 120 50.5'W	Buoy	264-726	79-82
Pt. Arguello, 34 33.3'N; 120 36.5'W	S.P.	9.9	79-80
Diablo Canyon, 35 12.5'N; 120 51.7'W	Buoy	75.6	84

1. Buoy = WAVERIDER accelerometer buoy
   Array = 4-gauge slope array for nearshore direction and energy
   S.P. = single point gauge for nearshore wave energy

sea level, average wind speed, and barometric pressure, in an effort to determine if there are relationships between these variables and observed wave and sea conditions (Figure 23).

Wave, wind, and tidal information is especially detailed in areas served by a major harbor, such as San Diego, Oceanside, San Pedro, and Santa Barbara. The effects of island sheltering have been established, at least qualitatively, for these locations, but there have not been enough deepwater wave climate studies to allow precise quantitative analysis of the effects of islands and banks on waves approaching the shoreline. Deepwater hindcasts are qualitatively useful, but contain significant quantitative imprecision. They are useful for general prediction of wave climate and height, but do not precisely predict nearshore wave climate.

In some harbor locations, the historical record extends 50-70 years, making some long-term discussion of oceanographic processes possible. For example, yearly mean sea level figures are available for the San Diego area for a period of 80 years (Figure 24). These records show both long-term trends (a rising sea level) and short-term fluctuations (coincident with El Nino events, in this case). Such

records allow some qualitative generalizations about ocean conditions during the past 80 years, but do not permit precise mathematical analysis.

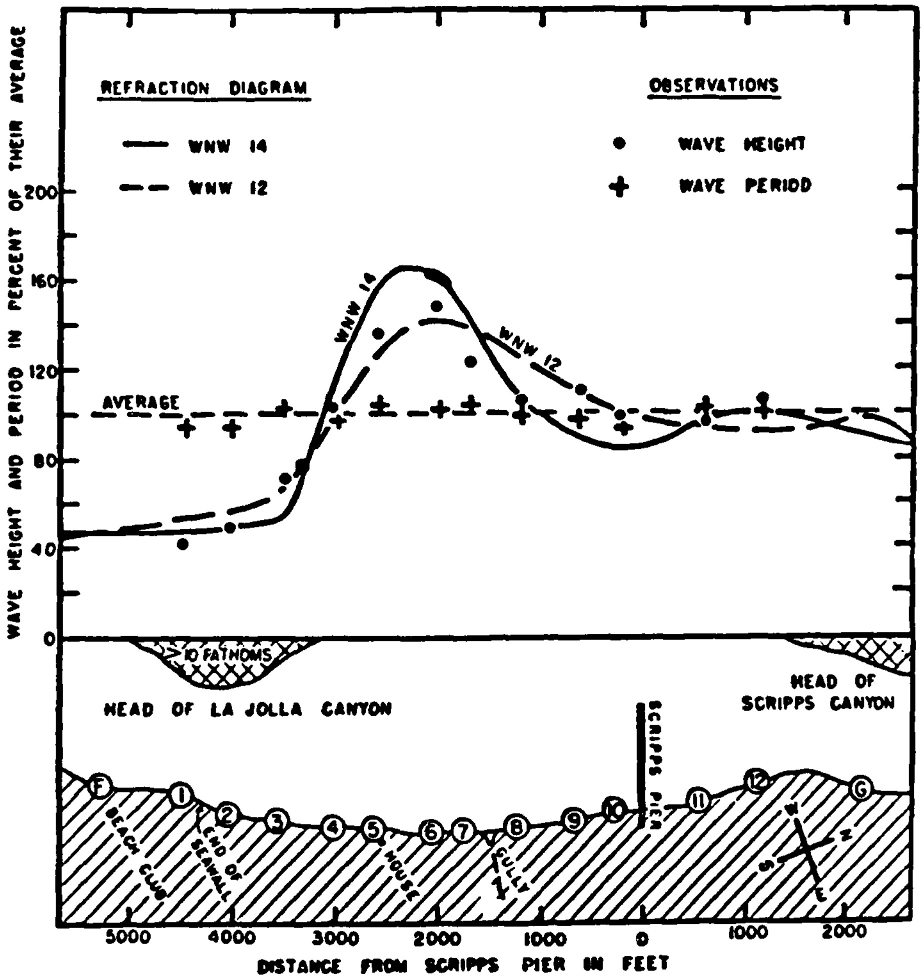


Figure 22. Observed and theoretical changes in wave height along Scripps Beach (Munk and Traylor, 1947).

On a more local scale, many of the littoral cells of the southern California coastline have been subjected to substantial review. The Oceanside Cell has been studied, for example, as a part of efforts to stabilize beaches around the city and harbor of Oceanside. Major losses of sediment from the beaches have been documented, and the conditions which caused these losses analyzed. Changes in littoral drift have been observed, and estimates of seasonal and net littoral drift made (Figure 25). As Figure 25 shows, longshore drift has been correlated to wave climate at Oceanside, albeit in a relatively general way. For some locations, then, a qualitative sediment budget is possible.

The data available in the literature are useful from a planning point of view, and in some locations provide a sound data base for further quantitative study. The

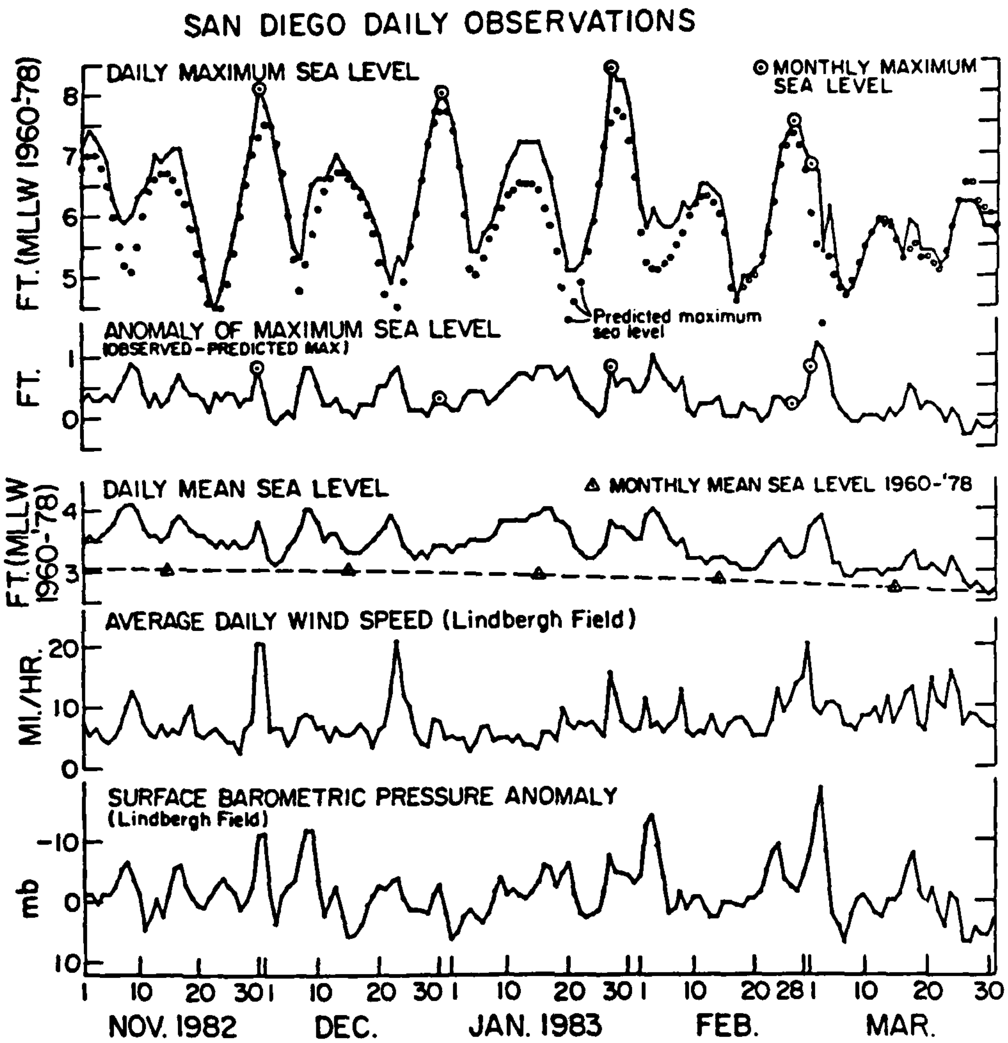


Figure 23. Daily sea level, atmospheric observations, and maximum predicted tide, winter of 1982-83, San Diego (Flick and Cayan, 1984).

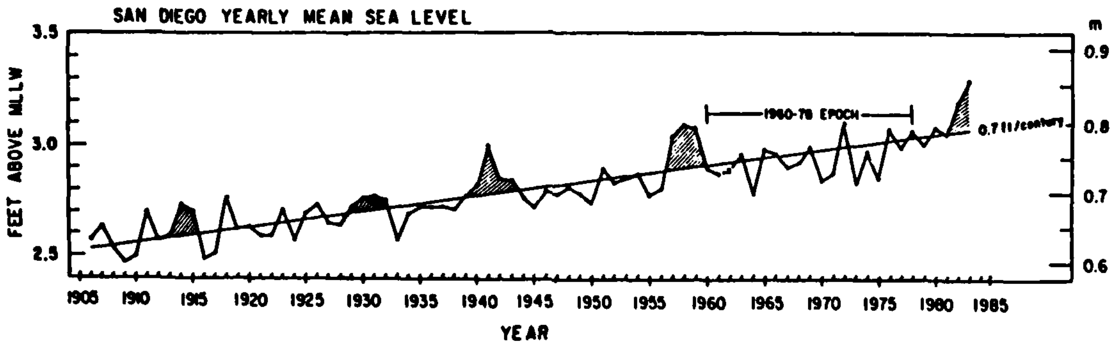


Figure 24. Yearly mean sea level above 1960-78 MLLW datum. Straight line shows secular increase of 0.7 feet/century. Shaded areas coincide with major El Nino episodes (Flick and Cayan, 1984).

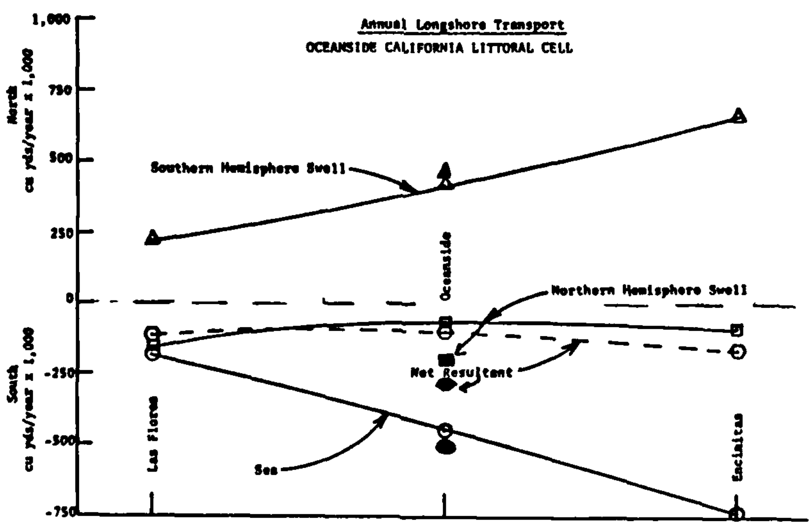


Figure 25. Annual sediment transport rates, Oceanside Cell. Open symbols are from Hales, 1978; filled symbols are from Inman and Jenkins, 1983.

weaknesses are a lack of systematic, simultaneous study of multiple variables such as currents, nearshore and deepwater wave climate, longshore currents, littoral drift patterns, winds, and tides. These factors need to be addressed systematically at key points along the southern California shoreline in order to establish the quantitative relationships necessary for development of sediment budgets for each littoral cell.

Despite the inadequacies in the available data, and the need for detailed quantitative study, the review of literature produced some valuable insights into coastal processes along the southern California coastline. Initially, review confirmed the validity of the littoral-cell approach which is central to CCSTWS. There was considerable discussion of littoral cells and their function. The boundaries of most cells in the southern California region have been established, and interactions between cells are being explored.

There is also a significant body of literature describing the processes of beach formation, and the general seasonal cycles of sediment movement onshore and offshore. Some questions remain about the extent of onshore and offshore movement of sediment, but an offshore bar-building stage in the winter, followed by onshore movement of the bar material during summer, is generally accepted as valid for most southern California beaches. Longshore transport is also at least theoretically understood, and there are formulas for estimating longshore transport from data about wave climate. Some of the more complex wave-beach interactions, such as cusp formation and formation and propagation of edge waves, are not precisely understood, but general theories to explain them are being explored at this time. A relationship between observed cusp height and observed wavelength of the swash cusp has been postulated.

Sediment discharge from rivers and streams has been studied in some detail in recent years, and the relationship between total river water discharge and sediment discharge has been established empirically for several southern California rivers (Figure 26).

General weather patterns were also found to have been well documented. Records of major storms and their pathways are adequate to permit investigators to define the more likely weather conditions for the region, at least conditions representative of the past 40-50 years. Relationships between surface water temperature and storm path and propagation are being explored, and the interaction between high and low pressure zones and storm track is well documented. Such a qualitative understanding paves the way for more precise quantitative study.

Major surface and subsurface currents along the coast have been identified in the past 15 years, and there are measurements of currrent direction and velocity for this period. A seasonal shift in current direction (north/south — summer/winter, respectively) has been established, and the transition period between dominant periods studied. Surface currents have been mapped, and the interaction of several currents is beginning to be understood. This work has been possible because of improved undersea transport and measurement. Tidal currents and currents set up by storm events are also being explored. Investigators have postulated that some longshore currents are the result of uneven build up of storm and tide driven water. The center of a storm may drive more water against the shoreline at one point than at another, the result being a pile-up of water at one point. Currents along the shore may be generated as water flows from the build-up point to areas

with less water driven against the shoreline. This relationship is proposed, but not quantitatively established.

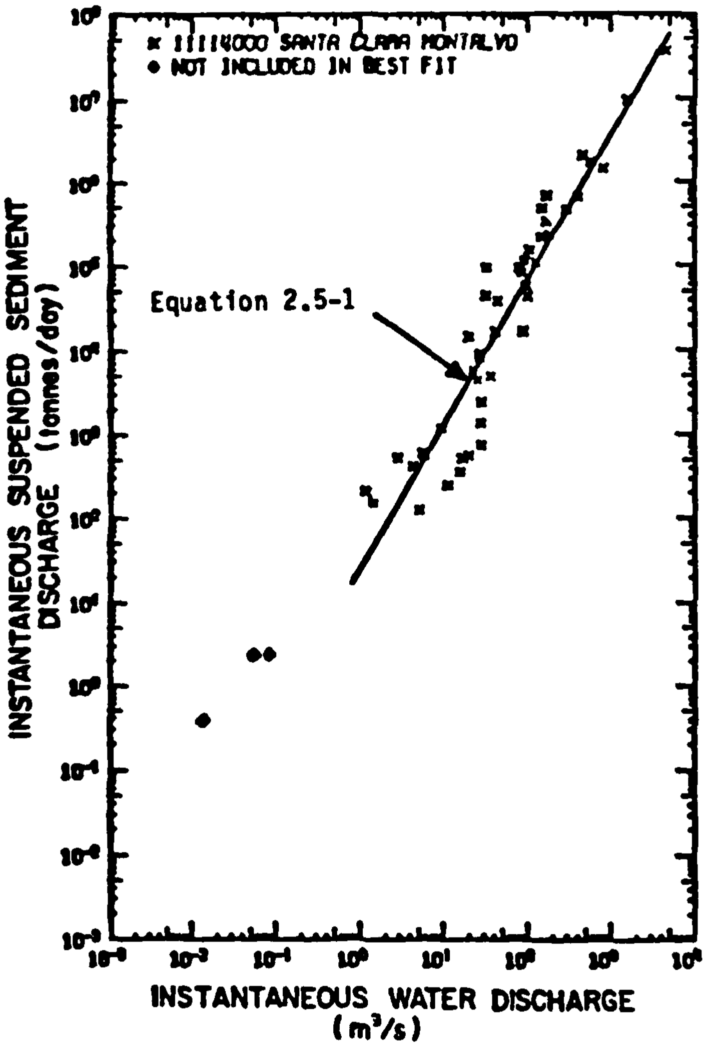


Figure 26. Relation of instantaneous sediment discharge to water discharge at Santa Clara River Station 11114000, 1969-76 (Brownlie and Taylor, 1981).

Knowledge of deepwater wave climate has improved considerably in recent years, and waves reaching the shoreline from remote locations can now be correlated to distant storm events of relatively known magnitude. The sources of deepwater waves approaching the California coast are being established, and the angles of approach for many locations are being calculated. Because of sheltering effects from offshore islands, however, wave climate may vary significantly within a reach of several miles. Detailed analysis of sheltering effects is thus necessary

before nearshore wave climate models can be developed. Nevertheless, researchers have established that summer season waves may reach the California coast from as far away as the Indian Ocean and the Ross Sea.

Finally, the literature dealing with wave modeling is extensive. Wave propagation, diffraction, refraction, and breaking models have been developed and it is possible to predict wave behavior to some extent. None of the models developed to date, however, accounts for the entire interaction of different chains of waves arriving at different intervals and from different directions. Nor do current models account for complex bathymetry and its effect on wave behavior. Such complex quantitative analysis remains to be undertaken, although there is no lack of scientific interest in this problem.

Overall, the progress which has been made in understanding coastal processes in the last 15-20 years has been significant. Researchers have succeeded in identifying the major factors which influence nearshore wave climate and currents, and thus shape the beaches. What remains is to establish interrelationships among variables, and to develop quantitative verifiable models of the interaction of all of the variables and the beaches.

NOTES

NOTES

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